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# Review of soil quality and trace element State of the Environment monitoring programmes

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# Review of soil quality, including trace elements, State of the Environment monitoring programme

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# Summary


### Project and client

- This project involved a stocktake and review of the soil quality and trace element State of the Environment monitoring programme. It is an essential step towards improving the national consistency of soil quality and trace element monitoring and data management to support the aims of the Environmental Monitoring and Reporting initiative, and the development of National Environmental Monitoring Standards.
- This project was undertaken for Hawke's Bay Regional Council, with funding from Envirolink (Advice Grant 1757-HBRC226).

### Objective

- To review soil quality and trace element State of the Environment monitoring and reporting to improve national consistency.

### Methods

- Web and literature searches using online search engines were undertaken to provide an overview of key international soil quality monitoring programmes.
- An initial workshop with a subset of the Land Monitoring Forum was held in February 2017 to finalise the review's scope and develop a survey to capture council data on soil quality monitoring programmes, including data management and reporting.
- These surveys were circulated by the Land Monitoring Forum, with follow-up, where required, by Landcare Research staff. The results of the individual surveys are captured in three data files with an overview and interpretation provided in this report, along with a strength, weakness, opportunities and threats (SWOT) analysis and high-level statistical review.

### Results and conclusions

- There was surprisingly limited information on soil quality programmes used internationally. An overview identified a number of different ones, including geochemical studies used to establish a geochemical baseline for the purpose of managing soil quality. These programmes may offer insights into solutions for gaps in the New Zealand programme.
- A detailed stocktake of regional and unitary council soil quality (including trace elements) monitoring programmes and data management identified similarities and differences in these programmes between councils. The detailed results of this stocktake are provided in three data files to allow further data interrogation. Following are some of the key points arising from the stocktake.
  - Twelve councils are currently undertaking ongoing soil quality monitoring, and a 13th is currently developing a programme.

- Sites established under the 500 Soils programme are used by nine councils, although not all 500 Soils sites are included in ongoing monitoring by three councils.
- Land use, often in combination with soil type, is used as the basis for site selection. However, there is variation in terms of how councils classify land use.
- Councils use a combination of sources for determining soil classification, although soil classification at some new sites has not been verified in the field.
- Site information recording largely follows that established by the Land Monitoring Forum (LMF 2009), with councils noting that generally more detail is collected now than previously.
- Most councils communicate with the landholder and obtain information on site management, and seven reports provided results to the landholder in the form of a copy of a relevant report, individual results or summary of results.
- Different naming conventions are used by councils for both site and sample identification.
- All but one council collect samples using a transect approach, although there some variations within this.
- There is considerable variation in the specific soil quality chemistry analyses undertaken, although pH and total carbon are always analysed, and total nitrogen, mineralisable nitrogen and Olsen phosphorous are typically analysed. Most soil quality chemistry analyses were undertaken by Landcare Research.
- For the physical soil attributes, bulk density and macroporosity analyses are undertaken by all but one council. Analyses were typically undertaken by Landcare Research, except aggregate stability, which was typically undertaken by Plant and Food Research.
- All councils undertake some form of trace element analysis, ranging from cadmium only to the analysis of 38 elements.
- Most councils aim to report differences between land use, change over time and comparison with guideline or target values. Most councils undertake basic statistical analysis (e.g. mean, median, range) on data for routine reporting. A smaller number of councils undertake more detailed analysis.
- Reporting is most often directed to a mixture of the general public and the science community. All but one council indicated that technical reports are produced, although the frequency varies. Two councils reported producing fact sheets or report cards on the results, while seven councils report online, typically by uploading pdfs of reports.
- Spreadsheets are primarily used to capture data, with varying systems and databases subsequently used.

**Recommendations**

- It is not intended that this project provide recommendations or solutions arising from the stocktake. The aim is to provide information that can be used to inform Environmental Monitoring and Reporting and National Environmental Management Standards processes. Nonetheless, there are some key aspects that stand out for consideration for further development, which came through a SWOT analysis.
  - Greater consistency of land-use classification between councils is required. In particular, consideration should be given to applying a consistent approach to specifying both farm system and land use at the time of sampling.
  - Consistency in the time of sampling minimises a source for variation in some soil properties, while consolidation and consensus relating to the appropriate target values to use would assist with consistent reporting.
  - Data management is an obvious weakness with different systems (processes and databases) being used by different councils.
  - Changes in site-naming conventions and loss of institutional knowledge through changes in personnel at individual councils create a challenging landscape for the accurate capture of historical data that can be confidently used to assess trends over time.

# Abbreviations

AMN – Anaerobically mineralisable nitrogen

CASH – Comprehensive Assessment of Soil Health

CEC – Cation-exchange capacity

EMaR – Environmental monitoring and reporting

ENVASSO – Environmental Assessment of Soil for Monitoring

FSL – Fundamental Soils Layer

GEMAS – Geochemical Mapping of Agricultural and Grazing Land Soil in Europe

HWC – Hot Water Carbon

HWN – Hot Water Nitrogen

LCDB – Land Cover Database

LMF – Land Monitoring Forum

NEMS – National Environmental Monitoring Standards

PFDI – potential P-fertiliser demand index

REACH – Registration, evaluation and assessment of chemicals

SoE – State of the Environment

TOC – Total organic carbon

VSA – Visual soil assessment

# 1 Introduction

Regional authorities and the Land Monitoring Forum (LMF) have been monitoring soil quality and trace elements since the Landcare Research '500 Soils' programme finished in 2000. A subsequent review by Hill et al. (2003) resulted in improvements and the publication of soil quality monitoring guidelines in 2009. The programme was initially designed to give regions flexibility in reporting on issues most relevant to their region. However, the Environmental Reporting Act 2015 requires a more uniform approach to national-level reporting.

Several recent reports, such as the Environmental Monitoring and Reporting (EMaR) scoping report (Jones et al. 2015) and *Status of Cadmium in New Zealand Soils* (Cavanagh 2014), have highlighted inconsistencies in monitoring. These inconsistencies have contributed to less than optimal State of the Environment (SoE) reporting in the Environment Aotearoa (2015) synthesis report. For instance, trace elements monitored by councils were not reported at all in that report.

This review is an essential step towards improving the national consistency of SoE reporting (including soil quality and trace element monitoring, and data management) to support the aims of the EMaR initiative, knowledge transfer, and national Environmental Domain reporting. The focus is on undertaking a thorough stocktake of data. This involves capturing the details of the data currently held, and how they are managed, to help inform the development of future monitoring and data management being developed through EMaR and National Environmental Monitoring Standards (NEMS) processes).

# 2 Background

The 500 Soils programme was a Sustainable Management Fund project that involved collecting soil quality data from approximately 500 sites nationally (roughly one site per 25 $km^2$) selected by the various participating regional councils over 1999–2001 (Sparling et al. 2000, 2001 a, b; Sparling & Schipper 2004). This programme set in place sampling methodology and tested a variety of possible indicators, selected from Doran & Parkin 1994 in consultation with New Zealand soil scientists from across Crown research institutes and research institutions.

After completion, the project and findings were reviewed (Hill et al. 2003) and a set of indicators for ongoing soil quality monitoring was formalised (Table 1). This formed the basis for the subsequent development of *Land and Soil Monitoring: A Guide for SoE and Regional Council Reporting* (LMF 2009), which provides guidance for undertaking soil quality monitoring.

**Table 1** Recommended indicators from the soil quality review (Hill et al. 2003)

| Soil property | Soil quality information | Applicable to: |
|---|---|---|
| Total carbon (C) | Organic C content | All soils |
| Total nitrogen (N) | Organic matter N status | All soils |
| Mineralisable nitrogen (AMN) | Readily decomposed organic N | All soils |
| Soil pH | Soil acidity | All soils |
| Olsen phosphorous (P) | P available to plants | All soils |
| Bulk density | Soil compaction | All soils |
| Macroporosity | Soil aeration and compaction | All soils |
| Quick test cations | Calcium, magnesium and potassium available to plants | Only necessary when nutrient status/balance is needed |
| Aggregate stability | Stability of soil crumbs | Cropping and horticulture soils |

Since 2000, regional councils have continued to add new sites and resample the original sites, and there are now approximately 1,100 sites across New Zealand. Some of these sites have been resampled three or four times. One of the initial goals of the 500 Soils project was the repeated sampling of sites over a number of years to assess temporal trends in the data. It was estimated that a minimum of between three and five repeated samplings would be necessary to ascertain if a trend was occurring. Councils have extended the parameters being analysed, with many councils now also monitoring one or more trace elements.

To maintain the ability to detect temporal change there have been few major changes in the programme since its inception. However, target values have been reviewed (Beare et al. 2007; Mackay et al. 2013) and new indicators are being trialed. New target values and indicators are based on updated or new scientific information.The Environmental Reporting Act 2015 sets out responsibilities for environmental reporting, the framework for reporting, and the timing for reporting products. Regional soil quality data have already been a significant input into the synthesis report (Environment Aotearoa 2015) and will feature in the upcoming Land Domain report.

To meet the requirements of the Environmental Reporting Act, the Ministry for the Environment (MfE), Statistics NZ and the regional councils through EMaR have been working together to establish a consistent approach to the measurement of soil health. This includes protocols for reporting on indicators, collecting more 'trend' data with sampling over six time points, and guidance to ensure greater spatial representation across regions and land uses.

The terms 'soil health' and 'soil quality' are often used synonymously, and uncertainty still remains over the distinction between the two. Doran and Parkin (1994) defined soil quality as "the capacity of a soil to function, within ecosystem and land use boundaries, to sustain productivity, maintain environmental quality, and promote plant and animal health." In contrast, the Cornell Soil Health Assessment (2014) considers soil health as 'dynamic soil properties' and soil quality includes both inherent and dynamic soil characteristics.

Dynamic soil properties are those properties that are susceptible to change as a result of soil use and management over years to decades. Inherent soil properties are those that are assumed to be stable over human lifespans and are used for soil taxonomy and classification of soils. Kibblewhite (2010) likens soil health to a relative measure of the system's performance in comparison to its optimum performance. Soil health evokes an image of soil as a living system, but, regardless of the specific connotation, the current trend does seem to favour the term soil health over soil quality. For the general purposes of this report, however, we use these terms interchangeably.

## 3 Objectives

- To review soil quality and trace element SoE monitoring and reporting to improve national consistency, including:
  - a brief literature survey of comparative soil quality (and trace element) monitoring programmes in an international context
  - a stocktake of other regional authority data sets and monitoring networks
  - a high-level review of the statistical design of the programme, the methods used for data collection and laboratory analyses, and identification of method inconsistencies and gaps in the data
  - a brief SWOT (strengths, weaknesses, opportunities, and threats) analysis (in relation to national-level reporting)
  - a description of current data management systems and procedures
  - taking into account current programmes and initiatives, including the EMaR land project, NEMS development, existing LMF knowledge, as well as current and proposed research programmes such as soil health and other sources of data (e.g. the Department of Conservation's soil monitoring programme).

## 4 Methods

Web and literature searches using online search engines were undertaken to provide an overview of key international soil quality monitoring programmes. In addition, selected regional council staff were asked to highlight any international programmes they were aware of.

An initial workshop with a subset of the Land Monitoring Forum was held in February 2017 to finalise the review's scope and develop a survey to capture council data on soil quality monitoring programmes, including data management and reporting. The survey was provided as an Excel workbook, which comprised four worksheets: an introduction to the survey, a list of survey questions (shown in Appendix 1), a worksheet to capture detailed sample analyses and laboratory details, and a worksheet to provide an inventory of samples used for soil quality monitoring.

To assist the survey participants, some questions had drop-down menus to select a response. Other questions required a text response. Where possible, council-specific surveys that were pre-populated with available sample information and publications provided as part of an earlier survey for the EMaR working group were provided. This enabled councils to focus on missing information and to cross-check, rather than collate, the information provided.

These surveys were circulated by the Land Monitoring Forum, with follow-up, where required, by Landcare Research staff. The results of the individual surveys are captured in three data files:

- Collated_Survey_Spreadsheet.xlsx
- Collated_analyte, lab metadata_Spreadsheet.xlsx
- Collated_Sampling Inventory_Spreadsheet.xlsx.

Summary and interpretation are provided in section 6, while section 7 provides a strength, weakness, opportunities and threats (SWOT) analysis and high-level statistical review.

## 5 Review of international soil quality monitoring programmes

Soil quality monitoring programmes have been developed for varying purposes internationally. Some programmes have a focus on general soil properties (e.g. pH, total carbon, cation exchange capacity, bulk density), while others have focused on geochemical analysis, with information on general soil properties collected as a secondary purpose (e.g. the GEMAS[1] programme).

This section provides an overview of key international programmes, detailing purpose, sample collection, parameters measured, and the status of the implications for using such information. A summary of the programmes is provided in Table 2, with more detailed descriptions following.

[1] Geochemical Mapping of Agricultural and Grazing Land Soil in Europe.

**Table 2** Overview of the national and international soil quality monitoring programmes

| Country | Soil monitoring programme | Purpose | Land uses | Sampling approach | Soil quality issues/indicators | Reference |
|---|---|---|---|---|---|---|
| New Zealand | State of the Environment reporting | State of the Environment reporting | All | Targeted sampling – multiple points along a transect | Soil pH, total C, total N, Olsen P, anaerobically mineralisable N (AMN), bulk density, macroporosity, aggregate stability | LMF 2009 |
| Australia | Soil Quality Monitoring in Tasmania | Soil quality monitoring to allow for improved soil management decision-making | All | Targeted sampling – multiple points along a transect | Soil pH, organic C, extractable P, exchangeable sodium percent, bulk density, aggregate stability | Cotching et al. 2010a, b |
| Europe | Environmental Assessment of Soil for Monitoring (ENVASSO) | Development of a harmonised soil monitoring programme for Europe | All | Grid-based sampling, plot sampling | 27 indicators covering soil erosion, decline in soil organic matter, soil contamination, soil sealing, soil compaction, decline in biodiversity, soil salinisation, landslides, desertification | Kibblewhite et al. 2010 |
| | Geochemical Mapping of Agricultural and Grazing Land Soil in Europe (GEMAS) | Baseline concentrations of trace elements to inform EU REACH risk assessment processes | Agricultural and grazing land | Grid-based sampling, plot sampling | Baseline concentrations for approximately 60 elements, including Al, As, Cd, Cr, Cu, Fe, Hg, Ni, Pb and Zn, and soil properties that influence the bioavailability of the trace elements, including pH, cation-exchange capacity, total C and S, particle size distribution | Reimann et al. 2014a, b |
| | Forum of European Geological Surveys (FOREGS) | Baseline concentrations of trace elements to inform soil quality and land management | All | Grid-based sampling, plot-based | Baseline concentrations of trace elements, including As, Cd, Cr, Cu, Hg, Ni, Pb and Zn | Salminen et al. 1998; Salminen undated; Lado et al. 2008 |
| United Kingdom | Geochemical Baseline Survey of the Environment (G-BASE) | Baseline concentrations of trace elements to inform soil quality and land management | All | Grid-based sampling | Baseline concentrations of trace elements including As, Cd, Cr, Cu, Fe, Ni, Pb and Zn | Johnson et al. 2005; Ander et al. 2011 |

| Country | Soil monitoring programme | Purpose | Land uses | Sampling approach | Soil quality issues/indicators | Reference |
|---|---|---|---|---|---|---|
| USA | Comprehensive Assessment of Soil Health (CASH) | Development of a framework to provide standardised, field-specific information on important constraints in soil health | Agricultural land | *Ad hoc* – as required by individuals | Physical indicators – soil texture, available water capacity, field penetrometer resistance, aggregate stability<br>Biological indicators – organic matter, ACE soil protein index*, soil respiration, active carbon content, potentially mineralisable nitrogen, root health<br>Chemical indicators – salinity and sodicity, pH, macro- and micro-nutrient content assessment, extractable potassium (K), extractable P, heavy metals | Moebius-Clune et al. 2016 |
| Canada | Sustainability of Canadian Agriculture | Assessment of the agriculture and agri-food sector's environmental performance for soil, water, air quality, farm land management, and food & beverage industry | Agricultural land | Soil landscape of Canada and agricultural census data | Indicators developed for soil, water, air, farm management (biodiversity), and eco-efficiency (of the food and beverage sector<br>Soil quality is assessed using 5 indicators: soil erosion risk indicator, organic carbon change indicator, soil salinisation risk indicator, soil contamination risk indicator, desertification risk indicator | Clearwater et al 2016 |

* Amount of  protein-like substances that are present in the soil organic matter

## 5.1 Soil Quality Monitoring in Tasmania

The SCEAM (Soil Condition Evaluation and Monitoring) project commenced in 2004, with the aim of establishing soil quality monitoring at permanent monitoring sites across a representative range of soil/land-use combinations in Tasmania. Ongoing monitoring could measure future change (on a 5-yearly basis) in selected soil quality indicators and provide a comparison to target values to improve soil management decision-making (Cotching et al. 2002b).

Six key soil quality indicators were used: pH, organic C, Olsen P, exchangeable sodium percent, bulk density, and aggregate stability, the latter two as indicators of structural condition (Cotching et al. 2010a). Target values for each indicator were dependent on soil order and land use, and were developed using expert knowledge and data on soil properties under a range of land uses held in the Tasmanian Department of Primary Industries, Parks, Water and Environment database.

Sites were selected depending on where:

- physical investigation had identified the required soil orders with appropriate land use
- regionally typical and spatially uniform soil profile characteristics were represented
- the landowner was cooperative.

The monitoring focused on agricultural land (northern and eastern areas), which was justified due to these land uses being more likely to result in soil degradation by anthropogenic activities than conservation or native forestry. The representativeness of soil orders and land uses in the SCEAM data set was estimated by comparing the frequency of sampling against the mapped area of each soil order and land use from published information (Bureau of Rural Sciences 2003; Cotching et al. 2009).

A soil pit was excavated at each site to 1.2 m depth (where possible) for full description, and classified to family level. Samples were collected from each major layer within the soil, with samples from any single layer bulked over a maximum 300 mm depth range. Bulk samples from every 2 m along the 50 m transect for both surface (0–75mm) and subsurface horizons (75 mm thickness cores between 75 and 300 mm depth, depending on horizon depths) were taken. All data were entered onto a Microsoft Access 2003 database with collated description, and data sheets are available on the Australian Soil Resource Information System website (http://www.asris.csiro.au).

## 5.2 Environmental Assessment of Soil for Monitoring (ENVASSO)

Environmental Assessment of Soil for Monitoring (ENVASSO) was funded from 2006 to 2008 as a scientific support to policy under the European Commission's 6th Framework Programme.[2] Its purpose was to develop a framework for a soil monitoring system across Europe and describe its potential implementation for protecting the continent's soils. An extensive literature review was carried out, which identified 188 key soil issues. A list of 290 potential indicators was produced (Huber et al. 2008), and a key set of issues and associated indicators selected using an expert consultation process. To assess soil status, nine key soil threats were identified: soil erosion, organic matter decline, contamination, compaction, salinisation, decline in biodiversity, soil sealing, landslides, and desertification.

As the complete set of proposed indicators was still too large, a sub-set of three priority indicators (TOP3 indicators) was selected for each soil issue (Table 2). This yielded 27 priority indicators although methods for monitoring wind erosion, tillage erosion, and C stocks in peat soils were found to be inadequate. As a result, 20 indicators were qualified for implementation, covering soil erosion by water, decline in soil organic matter, soil contamination, soil sealing, compaction, salinisation, and desertification.

A monitoring network with a density of one site per 300 $km^2$ covering most soil type and land-use combinations based on a grid-based sampling technique was recommended (Morvan et al. 2008). Monitoring activities and soil inventories were reviewed in the form of a survey conducted in all EU member states. Sampling strategies and testing protocols required for the estimation of indicators, as well as the frequency of re-sampling (for example, 10-year intervals), were identified (Arrouays et al. 2008). Protocols and procedures appropriate for inclusion in a European soil monitoring system were outlined (Jones et al. 2008), and 22 of these were used to test the indicators, methods and sampling design in 34 pilot studies to check the efficacy of the database (Micheli et al. 2008; Stephens et al. 2008).

The performance of these indicators was judged to be sufficient to support their early implementation within an operational soil monitoring system. However, there remained some relatively minor gaps that could not be filled within the ENVASSO project. Therefore ENVASSO recommended a concerted research effort by the scientific community, focusing on parameters, processes and model development in order to fill these gaps, so that these aspects of threats to soil could also be monitored robustly in the future (Jones et al. 2008).

## 5.3 Comprehensive Assessment of Soil Health (CASH)

The Comprehensive Assessment of Soil Health (CASH) was designed by Cornell University, USA, for farmers, gardeners, agricultural service providers, landscapers and researchers. It is a soil health assessment programme that provides standardised, field-specific information on important constraints in soil biological and physical processes, in addition to standard

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[2] http://esdac.jrc.ec.europa.eu/projects/envasso

nutrient analysis.[3] The framework was developed for New York and the north-eastern United States, but the indicators, concepts and frameworks were considered to be useful for the assessment and monitoring of soil health nationally and globally (Moebius-Clune et al. 2016).

The most important components of the framework are the selection and measurement of physical, chemical and biological indicators that represent critical soil processes; the development of scoring functions for these indicators that allow them to be interpreted; and the linkage of identified constraints (physical, chemical or biological) with management practices (Karlen & Stott 1994; Andrews, Karlen et al. 2002; Andrews, Mitchell et al. 2002). Forty-three potential soil health indicators were initially evaluated, from which 13 soil quality indicators were selected (Moebius-Clune et al. 2016). The selection was based on cost, consistency, reproducibility and relevance to soil.[4]

The following indicators were selected:

- **physical indicators:** soil texture, which relates to most soil processes and is important for the interpretation of other measurements; available water capacity, as an indicator of plant-available water; surface and subsurface hardness, as an indicator of soil compaction and rooting; and wet aggregate stability, as an indicator of structural stability
- **biological indicators:** organic matter content, as a measure of C-containing material; active C related to organic material, to support biological functions; ACE (autoclaved citrate extractable) soil protein index, as an indicator of the amount of protein-like substances present in the soil organic matter; soil respiration, as an indicator of metabolic activity of the soil microbial community; potentially mineralisable nitrogen, which relates to the ability of organic matter to supply N; and root health, which relates to soil-borne pest problems
- **chemical indicators:** salinity and sodicity; heavy metals; and soil chemical composition, which measures pH and macro- and micronutrients (Schindelbeck et al. 2008; Moebius-Clune et al. 2016), as given in Table 2.

Scoring functions, used to interpret soil testing, are equations that quantify the relationship between measured indicator values and soil health status. Scores from all indicators are synthesised into a comprehensive report that identifies specific soil constraints and provides management suggestions for the clients (Aubrey et al. 2016)**.** CASH scoring functions for each indicator were originally developed to interpret soil health measurements using data collected from north-eastern American soil samples analysed in the early 2000s (Andrews et al. 2004). In the decade since, the Cornell Soil Health Laboratory database has expanded,

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[3] https://soilhealth.cals.cornell.edu

[4] http://www.sare.org/Learning-Center/Books/Building-Soils-for-Better-Crops-3rd Edition/Text-Version/How-Good-Are-Your-Soils-Field-and-Laboratory-Evaluation-of-Soil-Health/Laboratory-Soil-Health-Testing

and more geographically diverse sampling representing over 60% of the United States and areas overseas has been undertaken (Aubrey et al. 2016).

In the context of CASH, scoring functions translate the measured value of a specific indicator to an interpretive rating via a curve that assigns scores between 0 and 100 to the measured values (Moebius-Clune et al. 2016). The mean and standard deviation of data sets are used to calculate the cumulative normal distribution function, which is essentially the scoring function as it converts the measured value to a unit-less value ranging from 0 to 100. As part of the CASH report summary, indicator scores are colour-coded red, orange, yellow, light green and dark green to classify values as very low (0–20), low (20–40), medium (40–60), high (60–80) and very high (80–100), respectively. The lower the CASH score, the greater the constraint on the proper functioning of processes, as represented by the indicator (Aubrey et al. 2016; Moebius-Clune et al. 2016).

## 5.4 Sustainability of Canadian agriculture

A set of science-based agri-environmental indicators to assess the environmental performance of the Canadian agriculture and agri-food sector in 2000 (McRae et al. 2000). These indicators cover soil, water and air quality, farm land management and resource use efficiency in the food and beverage industries and provide information on the overall environmental risks and conditions in Canadian agriculture. These indicators were developed following OECD protocols (OECD 2003) and are used to compare Canada's agri-environmental performance with that of other member nations. The set of indicators is assessed approximately every 5 years, with reports released in 2005 (Lefebvre et al. 2005), 2010 (Eilers et al. 2010) and 2016 (Clearwater et al. 2016).

Only the soil indicator is discussed here, with information on the other indicators provided in the reports previously listed. Soil health is measured by the development of key indicators to assess the following risks and trends in the effects of land use practices: soil erosion, soil organic C change, soil contamination (considering six elements: As, Cd, Cu, Pb, Se and Zn), soil salinisation, and desertification. The data used to populate the indicators are derived from previously developed models (e.g. rates of change in organic C, trace element accumulation), the National Soil Database and an agricultural census.

The soil organic carbon change (SOCC) indicator uses the Century model (NREL 2000) to predict the rate of change in soil organic carbon in agricultural soil arising from changes in land management practices (such as changes in tillage and changes between annual crops and perennial hay or pasture). The Century model, developed by Colorado State University, is a computer model which simulates carbon and nutrient dynamics for different types of ecosystems including grasslands, agricultural lands, forests and savannas (NREL 2000). In Canada, the Century model has been widely used to simulate SOC change for Canadian conditions (see Smith et al 1997 for original assessment of use) and is currently used for National Greenhouse Gas Inventory reporting (Environment Canada, 2017). The Risk of Soil contamination indicator uses a soil mass balance model to estimate trace element concentrations for the six key trace elements, with inputs based on the amounts of fertiliser, feed supplements and biosolids used per hectare on agricultural land, and loss due to leaching, crop removal and volatilisation. The concentrations predicted to be present after

100 years are compared to the Canadian soil quality guidelines (SQG)[5] and expressed as a risk quotient (RQ = concentration/SQG). The risk of soil salinisation indicator was developed to assess potential salinisation issues in the Canadian prairies.

## 5.5 Geochemical surveys

A number of geochemical surveys have been undertaken in Europe to develop baselines to assist with environmental management, among other reasons. The GEMAS project (Geochemical Mapping of Agricultural Soils and Grazing Land of Europe) is the most recent and extensive survey. It determined the geochemical baseline of almost 60 chemical elements to enable risk evaluations of naturally occurring substances under REACH (Registration, Evaluation and Authorisation of Chemicals) legislation adopted in December 2006 (EC 2006a).

The GEMAS project also determined soil properties (pH, TOC, CEC, total C and sulphur, particle size distribution) known to influence the bioavailability and toxicity of metals (and other elements) at the European scale. This project commenced in 2008 and the results were released in April 2014 as a set of two volumes (Reimann et al. 2014a, 2014b). The GEMAS survey collected more than 4,000 samples from 33 European countries, covering an area of 5.6 million km$^2$, at a sample density of one site each of arable land (0–20 cm) and land under permanent grass cover (0–10 cm), per 2,500 km$^2$ using grid-based sampling (Reimann et al. 2011). Strict guidelines and training were developed for sample collection and analysis to ensure consistency of the information provided (EuroGeoSurveys 2008; Reimann et al. 2011).

Analyses are typically undertaken on composite samples collected using a scheme similar to that shown in Figure 1 (the distances in the square could vary). These samples were collected from soil pits that also establish soil type and horizons (the pit was dug to the second soil horizon) or soil cores. At least one soil pit was dug at each location to establish soil type. In GEMAS, agricultural land was sampled to 20 cm while grazing land was sampled to 10 cm. Often the upper vegetated layer is removed, although roots remain (EuroGeoSurveys 2008). Several recent publications discuss the results of this project in detail (Reimann, de Caritat et al. 2012; Reiman, Filzmoser et al. 2012; Tarvainen et al. 2013; Reimann et al. 2014a, 2014b).

[5] http://ceqg-rcqe.ccme.ca/

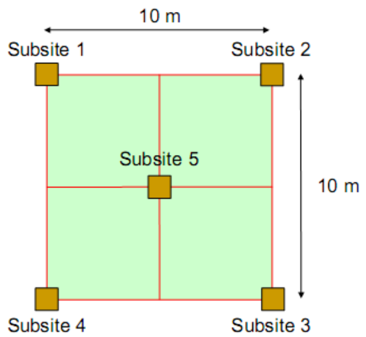


**Figure 1** Composite soil sampling scheme used in GEMAS. Soil samples are composited from five subsites from a plot 10 × 10 m square according to the above scheme.

Other geochemical surveys include FOREGS and G-BASE (United Kingdom), which also undertake grid-based sampling to determine geochemical baseline data for Europe. FOREGS (Forum of European Geological Surveys) started in 1993 and has been carried out by governmental institutions in 33 European countries (Lado et al. 2008). The FOREGS sampling grid was based on GTN grid cells (Global Terrestrial Network, also called Global Reference Network – GRN) developed to create Global Geochemical Baseline mapping (Darnley et al. 1995). Samples of stream water, stream sediment and three types of soil (organic top layer, minerogenic top and subsoil) were collected at 900 stations, each representing a catchment area of 100 $km^2$, corresponding to a sampling density of about one sample per 4,700 $km^2$ of cells, each cell being 160 × 160 km (Darnley et al. 1995).

The G-BASE project (Geochemical Baseline Survey of the Environment) is one of the British Geological Survey's core strategic projects. It commenced in the late 1960s, when it was predominantly concerned with mineral exploration. It has now evolved into a systematic, high-resolution regional geochemical survey producing baseline data relevant to many environmental issues. The aim of the project is to support UK environmental sustainability and development, in addition to determining 'normal' concentrations of contaminants in soil in the United Kingdom, to assist in the management of contaminated land (Ander et al. 2011).

Soil samples are collected at scales ranging from one sample per 2,500 $km^2$ (GEMAS data) to one site every 25 $km^2$, and include more detailed collection at urban (4 sites/$km^2$) and rural (1 site/2 $km^2$) scales. These samples are taken from the surface (0–15 cm) and from a depth of 35–50 cm as a composite of material taken from five holes distributed at the corners and centre of a 20 m × 20 m square (Johnson et al. 2004).  Details of the sampling methods and analysis protocols can be obtained from various sources (Johnson et al. 2003, 2005; Johnson & Breward 2004; Ander et al. 2011).

## 5.6 Summary of overseas soil monitoring programmes

The different systems incorporate many different indicators, utilise data at different scales, and employ different metrics for scoring. A common theme throughout the programmes is that biological indicators are often lacking, because they are expensive to obtain, often highly variable, and difficult to put critical limits or metrics on. To a large extent contaminants (primarily trace elements) are minimally covered in the existing soil health programmes (which are largely focussed on agricultural land) ie they generally form only one indicator of many. However, in the context of agricultural, in particular pastoral, land this is a reasonable approach as the environmental risk from contaminants is anticipated to be low and contaminants are likely to only gradually accumulate. The critical aspect is that information on soil contamination is included as part of the soil health measures – effectively as an early warning system. In contrast, the geochemically based programmes focus on trace element concentrations and include typical 'soil quality properties' from the perspective of how they may influence the bioavailability of the trace elements. The purpose of these programmes is to establish geochemical baselines to assist in managing soil quality rather than assessing soil health *per se*.

The Canadian system differs in that it relies more on derived data at a broad level (e.g. Census of Agriculture) rather than actual soil measurements. The US, although not having a truly national programme, probably has the most advanced numerical indexing system in the Soil health Management Assessment Framework (SMAF) (Andrews et al. 2004). This system utilises algorithms to generate continuous curves for indicator scoring. The system produces a numerical score for each indicator group and then combines these scores into a single soil health number.

While this approach has advantages in that a single soil health number can be compared across sites, it also oversimplifies soil health reporting because there are often trade-offs in different facets of soil health, and averaging all numbers may mask differences in indicator groups. For instance, for two sites having the same score, one site may have consistent values around that average value, while another site may have some very high and some very low scores. Letey et al. (2003) and Sojka et al. (2003) are fairly critical of the soil health concept in general, but over-simplification of scoring was one of their major complaints.

The New Zealand approach is a pragmatic approach that utilises a minimum data set as an early warning system to signal major issues with soil health rather than trying to measure all aspects of soil health at once. Although it could be criticised for not being overly comprehensive, it is cost-effective, so that participating regional councils (even smaller ones) have been able to continue monitoring over a number of years even when competition for dollars within council budgets is high. In comparison, while the European (ENVASSO) programme was very thorough in its sampling approach over much of Europe, the sampling was never repeated because of the cost. However, the flexibility of the New Zealand programme has led to some issues for national reporting.

# 6 Stocktake of regional council soil quality data

## 6.1 Soil quality monitoring overview

Responses were received from all 16 regional and unitary councils, with 13 councils returning a completed survey. Of the people involved in completing the survey, five had worked in soil quality for 1 year or less and six had worked at their respective council for less than 5 years.

An overview of the status of soil quality monitoring by regional authorities is provided in Table 3. Twelve councils are currently undertaking soil quality monitoring for State of the Environment reporting, and Gisborne District Council is currently developing a soil quality monitoring programme and provided responses to a number of the survey questions. Horizons Regional Council commenced more formal soil quality monitoring in 2015 but had previously undertaken soil quality assessments using visual soil assessments (VSAs). Environment Southland has undertaken soil quality sampling since 2010 and is currently undertaking a review before the next round of sampling planned for 2018.

The majority of councils commenced monitoring at the time of the 500 Soils programme (from 1999 to 2001), with nine councils including some or all 500 Soils sites in ongoing monitoring generally, in addition to other sites. The 500 Soils sites were not used by those councils that had commenced monitoring more recently (i.e. Horizons Regional Council, Environment Southland and Gisborne District Council). Otago Regional Council, West Coast Regional Council and Nelson City Council have no plans to commence soil quality monitoring, for a combination of reasons, including lack of need, and/or budgetary and capacity constraints.

Eight councils indicated that monitoring had been discontinued at some sites, with the most common reasons being changes in land use (to unsuitable, or not of interest for sampling, including site being built upon) and landholder objections/access restrictions. Another reason was lack of certainty about the location of previously sampled sites. Two councils also indicated that some 500 Soils sites were not resampled because the needs of the council had changed. One council indicated no discontinuations, although one site had not been resampled since 2001 and the majority of the other sites have been sampled once recently (from 2014).

Environment Southland has yet to undertake resampling, although it was noted that some sites have poor metadata and a review of sites is required to determine suitability for resampling, so some sites may be discontinued. Horizons is discontinuing some sites that had been monitored using VSA due to the change to formal soil quality monitoring, with other sites discontinued due to landowner or land-use change.

For the 500 Soils sites, seven councils had records of the 500 Soils site information sheet, two did not, and one was unsure. Three councils did not answer this question. Staff turnover, lack of knowledge (of the programme) and having no need for this information appear to be likely explanations for the absence of this data. Most of the councils that did not have the data sheets had respondents who were relatively new to the soil quality area.

Also, councils that have more recently commenced soil quality monitoring have not used these sites, and therefore there is no need for that information. These information sheets are available in Sparling et al. (2000, 2001a, b).

Six councils indicated that additional soil quality studies had been undertaken, including studies on urban soils, soil characterisation studies and compaction studies. A list of publications from each council is provided in Appendix 2.

**Table 3** Summary of the status of State of the Environment soil quality monitoring by regional and unitary authorities in New Zealand

| Council | SOE monitoring | Other soil quality investigations | Year commenced | No. of current sites | Includes 500 Soils sites? | Any sites discontinued ? | Comment |
|---|---|---|---|---|---|---|---|
| Northland Regional Council | Yes | | 2001 | 29 | Yes[1] | No | |
| Auckland Regional Council | Yes | Additional studies | 1995 | 124 | Yes | Yes | |
| Waikato Regional Council | Yes | Additional studies | 1995 | 156 | Yes | Yes | |
| Bay of Plenty Regional Council | Yes | Additional studies | 1998 | 82 | Yes | Yes | |
| *Gisborne District Council* | *About to commence* | *N/A* | *?* | *50* | *No* | *No* | |
| Hawke's Bay Regional Council | Yes | | 2000 | 86 | Yes | Yes | Not all original 500 Soils sites resampled |
| Taranaki Regional Council | Yes | | 1998 | 20 | Yes | Yes | Not all original 500 Soils sites resampled |
| Horizons Regional Council | Yes[2] | | 2015 | 41 | No | No | All sites sampled once |
| Greater Wellington Regional Council | Yes | Additional studies | 2000 | 118 | Yes | Yes | |
| Tasman District Council | Yes | | 2001 | 35 | Yes | No | 14 sites resampled once, remaining sites sampled once |
| Nelson District Council | No | N/A | N/A | N/A | N/A | N/A | N/A |
| Marlborough District Council | Yes | Additional studies | 2000 | 92 | Yes | Yes | |
| Environment Canterbury | Yes | Additional studies | 1999 | 314 | Yes | Yes | Not all original 500 Soils sites resampled |
| West Coast Regional Council | No | N/A | N/A | N/A | N/A | N/A | N/A |
| Otago Regional Council | No | N/A | N/A | N/A | N/A | N/A | N/A |
| Environment Southland | Yes, but on hold until 2018 | | 2010 | 57 | No | No | All sites sampled once |

[1] Survey respondent indicated no, but cross-check of site information shows that all sites are the original 500 Soils sites.

[2] Previously VSA surveys in summers of 2002/03 and 2004/05, VSAs on land management index sites in the region in 2006, some VSAs on farm plans.

## 6.2 Site establishment

As shown in Table 3, nine councils include some or all sites established under the 500 Soils programme in their SOE monitoring programme, so the basis for the selection of those sites is covered in the relevant reports (Sparling et al. 2000, 2001a,b). Twelve councils indicated that non-500 Soils sites were used for SOE monitoring. Where new sites have been established, land use − most often in combination with soil type − is used as the basis for selection, which is consistent with LMF 2009. New sites were typically established to cover land uses under-represented by 500 Soils sites and to meet the needs of councils. Two councils use aerial photography to assist with site selection, and one council also considered land-use history. Ease of access is also a consideration for two councils.

A summary of the land-use categories used by different councils, and the specific land uses falling within those categories, is shown in Table 4. However, some councils did not specify the land uses included within the general land-use categories. Most councils based land-use classification on specific information about the site, while one council based land use on Land Cover Database (LCDB) classes.

There are a number of inconsistencies in land-use classification between councils. For example, market gardens could be captured in one of three categories: horticulture (one council), cropping (three councils) or as a separate category.  Dairy and dry stock were typically recorded by councils, although the basis for classification was variable. One council specified dairy as being the milking platform only (i.e. milking cows), with dairy run-off (non-milking cows) included as dry stock. Most councils did not make this distinction, which means the extent to which non-milking cows are included in each category is unclear. Further discussion on the challenges and implications of land-use classification is provided in section 7.1.1.

Another council used irrigation as the primary way to distinguish between dairy and dry stock, with dry stock being any non-irrigated land.  One council indicated that dairy and dry stock were a subset of pasture sites, although in soil quality information provided by this council all three categories were used at the highest level i.e. dairy and drystock were not considered a subset of pasture sites. Where mentioned, deer were generally included as part of dry stock, although one council included them as a separate category.  Native vegetation or background sites was sampled by seven councils, with two councils combining exotic and indigenous forestry.  Urban land use was only specifically sampled by two councils.

Once the general site has been selected, all councils ensure the specific site for sampling avoids obvious disturbances such as gateways, water trough, vehicle tracks, livestock paths, or obviously wet or dry areas. All councils currently locate the site using GPS, with map references having been used for older sites. Councils also mentioned including a description of the site and photographs to assist with site identification.

**Table 4** Specific land use monitored and included within defined land-use categories used by individual councils

| Council | Horticulture | Cropping | Dairy | Dry stock | Pastoral | Forestry | Native/ background | Urban | Other |
|---|---|---|---|---|---|---|---|---|---|
| NRC | ✓ | × | ✓ | ✓ | ✓ | ✓ | × | × | × |
| ARC | Orchard<br>Vineyard/ viticulture | Market garden; outdoor vegetable production, nursery | Dairy | Sheep<br>Cattle<br>Deer | Pasture | Plantation forestry (exotic pine) | Native bush | ✓ | Lifestyle block conversion |
| WRC | Orchard<br>Vineyard | Arable[3] | Subgroup of pasture<br>Dairy cows | Subgroup of pasture –sheep, beef, deer | Dairy<br>Dry stock<br>Cut & carry | Production | Native vegetation | × | × |
| BoPRC | Orchard<br>(kiwifruit) | Maize | All types & management (i.e. irrigated, organic) | Sheep<br>Beef<br>Grazing | × | Cultivated | Indigenous forestry | × | Deer |
| HBRC | Orchard and vineyards | ✓ | ✓ | Intensive and extensive | Intensive and extensive | ✓ | Native forest remnants<br>Trees | × | × |
| HRC | Vegetables | Mixed cropping within sheep and/or beef farms | ✓ | Sheep & beef<br>Beef<br>Sheep | × | × | Native bush | × | × |
| TRC | × | Maize, market garden | Lifestyle blocks<br>Organic & standard dairy practices | Sheep & beef | ✓ | Plantation | Native<br>Indigenous vegetation | × | × |
| GWRC | Viticulture<br>Pipfruit | Extensive (wheat, barley, seed crops) | Milking platform | Sheep & beef<br>Dairy run-off<br>Deer | × | Exotic (pine) | ✓ | × | Market gardens |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| TDC[1] | Orchard<br>Vineyard | Cropland | × | × | High-producing grass, low-producing grass,<br>Tussock grassland, depleted grassland | Harvested deciduous<br>Hardwood indigenous<br>Exotic | × | Built-up<br>Urban park<br>Transport infra-structure | × |
| MLDC | × | Corn, peas, carrots, wheat, barley, etc. | Irrigated pasture | Non-irrigated pasture | × | Exotic and native vegetation | × | × | Viticulture |
| Ecan | × | ✓ | ✓ | ✓ | ✓ | ✓ | × | × | × |
| ES | <1,000 ha & leases land from dry stock[2] | × | Pastoral | Pastoral intensive (flat) and pastoral extensive (hill and high country) | × | Exotic (pine) | × | × | × |

NRC – Northland Regional Council, ARC – Auckland Regional Council, WRC – Waikato Regional Council, BoPRC – Bay of Plenty Regional Council, HBRC – Hawke's Bay Regional Council, HRC – Horizons Regional Council, TRC – Taranaki Regional Council, GWRC – Greater Wellington Regional Council, TDC – Tasman District Council, MLDC – Marlborough District Council, Ecan – Environment Canterbury, ES – Environment Southland

[1] Land use based on LCDB cover class. [2] Not selected as a target land use, [3] Soil cultivated at least annually, including grain crops, vegetables

Site information captured (or planned to be captured) by individual councils at the time of site establishment is generally consistent, with the majority of councils including all the criteria in LMF 2009 (Table 5). Most frequently not captured was land use during the previous 10 years, with only half the councils capturing this information. The majority of councils include information on parent material, although no council indicated how parent material was determined (this question was also not entirely clear that this was being asked for).

**Table 5** Site metadata recorded at time of site establishment

| Data | Response |
|---|---|
| The person undertaking the sampling, and their affiliation | 11 yes, 2 No (TRC, TDC) |
| Physical location (e.g. Fern Farm, Tui Road, Shannon) | 13 Yes |
| Landowner or manager, and their postal address | 13 Yes |
| Local contact person | 13 Yes |
| Map reference | 8 Yes, 6 No |
| GPS (state projection used; e.g. NZTM, NZMG ) | 13 Yes |
| Soil series and soil classification | 13 Yes (12 soil series, 3 NZSC) |
| Farm system (e.g. dairy farm) | 13 Yes |
| Current land use | 13 Yes |
| Land use during the previous 10 years | 6 Yes, 6 No |
| Present vegetation | 12 Yes, 1 No (TDC) |
| Slope | 12 Yes, 1 No (TDC) |
| Elevation | 9 Yes, 3 No (BoPRC, TDC, HRC) |
| Landform (as per Milne 1995) | 9 Yes, 2 No (BoPRC, TDC), 2 unsure (NRC, Ecan) |
| Annual precipitation | 8 Yes, 3 No (Auckland, BoPRC, Southland) |
| Parent material (how was this determined?) | 8 Yes, 2 No (BoPRC, Southland), 2 unsure (HBRC, TDC), |
| Soil drainage class (as per Milne 1995) | 10 Yes, 2 No (TRC, Southland) , 1 unsure (Ecan), |
| The nature and date of any extreme events such as flooding, landslips | 3 yes, 9 No |

All councils that are undertaking, or plan to undertake, soil quality monitoring responded that both farm system and land use at site is recorded. However, in data sets provided to Landcare Research for other projects, this information is not obvious and/or there is inconsistency in classification of land use, so it is unclear what information refers to farm system and what information refers to paddock at time of sampling. All councils indicated that GPS locations were recorded, although the responses to which projection were variable. Where map reference is used, this was primarily in relation to older sites. All councils indicated that soils series and classification were recorded, with the majority of councils using the New Zealand genetic classification, only three councils reporting both soil series and New Zealand Soil Classification (NZSC), and two councils (including Gisborne) using NZSC only.

Councils used a combination of sources for determining soil classification (Table 6). While original 500 Soils sites were verified by a pedologist, soil order at some new sites has not been verified in the field. Some councils have relied solely on soil maps to determine soil classification. Soil polygons are often made up of several soils, with the dominant soil sometimes making up less than half of the map unit. Misidentification of soils has two consequences: 1) since some target values differ by soil order, target values may not be applied properly, and 2) stratification by land-use/soil order combinations may not be accurate.

Five councils also indicated they captured site management history, while five indicated they did not. Two councils did not respond. Ten councils indicated they held soil profile information, while two did not.

Different naming conventions are used for site identification, including a single site number, combined land-use identification and site number, project identification (e.g. '500' for 500 Soils sites) and site number. No councils have retained original 500 Soils site identification, with consistency of site naming and meeting council needs the key reasons for changing identification. However, the 500 Soils site ID is retained by some councils as the sample ID for the samples that were collected at that site under the 500 Soils programme.

There is a separate Envirolink project looking at naming conventions (Ritchie), and a uniform naming system is strongly encouraged because it will make data verification and data provenance much more streamlined. The different naming systems (and changing naming systems) make data verification for past data difficult, as laboratory data sheets for sites originally sampled during the 500 Soils project are named with the original 500 Soils site names, but later resampling data have changed naming conventions, and correlating the different naming conventions is difficult.

**Table 6** Basis for classifying soils at soil quality sites

| Council | Determination of soil type | Soil chemistry and other measurements undertaken on a one-off basis to assist soil classification? |
|---|---|---|
| **Northland Regional Council** | Mostly under 500 Soils programme | |
| **Auckland Regional Council** | Soil profile information has also been collected at each site. A basic soil profile description, including horizons, depths, colour and texture, combined with potential rooting depth and character of any limiting layer, is also completed. | Yes |
| **Waikato Regional Council** | Field soil description backed up by chemical analysis (e.g. total C content, P retention). | Yes, P retention, CEC |
| **Bay of Plenty Regional Council** | Field-based soil profiles descriptions were originally used. | Yes, the analytes recorded at any round of sampling also included analytes of interest at the time, limited hot water C and resin P samples were taken in 2015 as part of a gaps analysis for the Rangitāiki River catchment. The trace elements analysed have varied from a 33 element suite to, in 2014/15, only heavy metals, and have now returned to the 33 element suite. |
| **Gisborne** | Anticipate engaging a suitably qualified pedologist to provide a field-based soil-profile description for each of the 50 sites. | Yes. There are some one-off tests they anticipate doing on the first round, and guidance is been sought from other regional councils. |
| **Hawke's Bay Regional Council** | Predominantly using profile descriptions at the time of site establishment. Soil maps were also used to verify soil profile descriptions. | No |
| **Taranaki Regional Council** | Soil database GIS, maps of total soil composition in Taranaki, field-based soil profile description | No |
| **Greater Wellington Regional Council** | A Landcare pedologist did it under the 500 Soils programme | Yes, originally by Landcare, but in some cases not. More recently a check of sites was done and CEC, anion storage capacity at 0–10 cm was measured on samples (if a sample was available or retained) |
| **Tasman District Council** | Experience, soil maps | Yes, P retention, cation exchange capacity, Ca, Mg, K, Na, NO3-N, NH4-N, AMN, particle density, total porosity, available water (various), aggregate stability, rainfall, altitude |

| | | |
|---|---|---|
| **Marlborough District Council** | Field-based soil profile | Yes |
| **Environment Canterbury** | Soil maps, although checked against a shallow profile. | Yes, particle size analysis of the surface sample, mainly to distinguish between the soils forming in loess from soils forming in alluvium. Thinking of collecting some diagnostic data from the B horizon, such as P retention |
| **Environment Southland** | Topoclimate South soil map and some by person sampling. Not 100% sure for all sites. | Yes, P retention |
| **Horizons Regional Council** | Field-based soil description | Yes, Anion Storage Capacity (ASC) on some, texture on some, CEC on some. |

## 6.3 Sample collection

Seven councils undertake sampling in spring and four in autumn; one council has undertaken sampling in both spring (soil quality monitoring) and autumn (mapping projects). One council indicated that resampling would be done at the time of year of the original sampling – which was February to May. Generally an effort is made to sample cropping sites before harvest.

Ten councils collect samples using the transect approach, as established in the 500 Soils programme. The remaining councils typically use a variation of the transect approach (e.g. 20 cores along a 40 m transect), and three fixed sampling locations (i.e. replicates) established along the transect (soil chemistry and physics). One council undertook sampling of 10 samples along a 100 m transect length in one year, with 50 m and 25 m transects used in the subsequent year. For non-500 Soils sites collected by Ecan, three replicate samples randomly located in a paddock are collected at 0–15 cm and 15–30 cm. One council further noted that urban soils were collected to 30 cm (0–15 and 15–30cm), although this was for a specific study, some sites from which may be included in the soil quality monitoring programme.

GPS is currently used by all councils to locate sample sites, with GPS readings taken at different points by individual councils; four councils report only start point; four councils report start and end points; two record start of transect and bearing; one records start, end and length of transect; one reports start, end and middle; one records only a single point with no further detail; and one uses three fixed sampling points at each site. There was a limited response to what co-ordinate system is used, and from previous experience there is a mix between NZTM and NZMG, with NZMG more often used for earlier-established sites.

Other specific differences in sampling are noted in Table 7. While there is an overall protocol for sampling along the transect, there is some confusion about how to sample in specific circumstances, such as under heterogeneous surface microtopography (e.g. furrows, humps and hollows). Most councils are aware of the difference in macroporosity measurements, but there can be ongoing confusion because of turnover of staff. Macroporosity is a general term, which literally means ‘large pores’. Current macroporosity target values are defined based upon the measure: total porosity – soil water content at –10 kPa. The Landcare Research soil physics laboratory uses the technical definitions set down by the NZ Soil Bureau, which calls the ‘total porosity – soil water content at –10 kPa’ measurement ‘air filled porosity’, versus ‘total porosity – soil water content at –5 kPa’, which it refers to as ‘macroporosity’. So councils need to be aware that if they use the Landcare Research soil physics laboratory, ‘air filled porosity’ is the measure of macroporosity they should be reporting. Noting the soil water potential when referring to macroporosity measurements has been suggested as a way to help avoid confusion; for example, ‘Macroporosity (–5 kPa)’ or ‘Macroporosity (–10 kPa)’).

Also, there is some disparity in when sampling occurs among different councils. Occasionally sampling has been done under very dry conditions, resulting in shattered cores for soil physical analysis. Although we recognise that councils generally have a relatively short window in which to get sampling done, sampling should not occur when the soil is either very wet (i.e. saturated) or very dry.

Six councils indicated that the sample collection over time had not changed, while three indicated specific changes, including an increase in the number of plug samples, changes in the coring device, and collection of samples for SPLP (synthetic precipitation leaching protocol). Five councils were unsure of any changes due to lack of knowledge, primarily due to staff turnover.

All councils have a specific protocol for labelling samples, although these protocols differ. Protocols include unique identifiers based on council-year-site number (e.g. TDC12.21, which refers to Tasman District Council, 2012, site 21), year-land use-sample number (e.g. 2016EP01 (2016 extensive pasture, sample 1), although for the latter it is unclear how site ID is captured. One council does not use a unique sample ID but uses the site ID as the sample ID, with date of sampling used to differentiate between samples collected at different times. One council indicated that due to changing over to a database system, a unique site identifier is required, and site ID (and presumably sample ID) will change.

**Table 7** Variations in specific aspects of sample collection

| Item | Response |
|---|---|
| Collection of samples on land with furrows or rows (e.g. vegetable cropping, vineyards) | Out of 14, 5 do across (in & between rows); 3 do along, including GWRC, HRC and HBRC. (HBRC do along − for orchards/vineyards, 2 transects were established at each site: 1 transect in a planted row and a 2nd transect between rows). MLDC include some sites with row and inter-row sampling in vineyards. 2 councils did not respond. |
| Sample collection for macroporosity and bulk density | 8 councils as per LMF guidance (75 × 100 mm ring at 15, 30 and 45 m along transect); 1 council collects 3 samples at 0, 20 and 40 m along transect; 2 councils collect at 0, 25 and 50 m along transect; and 1 council indicated sampling every 2 m along the transect. |
| Are you aware there are different matric potentials for macroporosiy (i.e. air capacity vs macroporosity)? | 10 Yes, 3 No |
| • What do you use/report? | Varies - 5-1500, only -5 and -10 kPa or both, and includes air filled porosity |
| Collection of samples for aggregate stability | 10 as per LMF guidance. Out of these, 1 is only for horticultural sites (ARC) and another 1 only for cropping sites (HBRC); 2 (Southland, BoP) councils don't collect samples for aggregate stability; 1 council didn't respond. |

The site information captured at the time of sampling is shown in Table 8, and is generally consistent between councils and covers the criteria included in LMF 2009. Some councils noted there has been a change in information collected over time, with more information typically collected now. Site information recorded at the time of sampling that is of value to councils is land use (particularly more specific information on vegetation present, soil type, state of pasture and cropping history, including time since last cropped) and stock class.

**Table 8** Information collected at the time of sample collection

| Item | Response |
|---|---|
| The person undertaking the sampling and their affiliation | 11 yes, 2 No (HBRC, TDC)) |
| Any changes to landowner or manager, and their postal address and local contact person | 12 yes, 1 No (TDC) |
| GPS (state projection used e.g. NZTM, NZMG ) | 12 yes, 1 No (BoP), |
| Soil series and soil classification | 7 Yes, 6 No |
| Current land use | 13 Yes |
| Present vegetation | 11 yes, 2 No (NRC, TDC), |
| State of site (e.g. site just harvested) | 11 yes, 2 No (NRC, TRC). |
| The nature and date of any extreme events such as flooding, landslips | 9 yes, 4 No |

Nine councils indicated they asked the landowner about land management using a variety of methods: survey prior to or given at time of sampling, phone call, conversation at time of sampling, etc. Information on land management that was indicated to be of value to councils includes information on fertiliser management (history, time since last application), irrigation, land-use history, crop rotation and grazing management.

Frequency of resampling of site varies between councils (Table 9), with weather, farmer requests, budget, skilled personnel and time constraints all listed as factors influencing resampling time. The majority of councils relocate the site using GPS, one council indicated return to same paddock, and two councils have not undertaken return visits.  Site photos may also be used.

Inventories of all samples collected by each council for State of the Environment soil quality monitoring are captured in the *Collated_Sampling Inventory_Spreadsheet.xls* file.

**Table 9** Frequency of sites resampled by individual councils

| Council | Frequency of site resampling (years) | Land uses |
|---|---|---|
| Northland Regional Council | 5 | All |
| Auckland Regional Council | 5 | All |
| Waikato Regional Council | 5 | All |
| Bay of Plenty Regional Council | 5 | Horticulture (kiwifruit) |
| | 3 | Cropping (maize) |
| | Previously 5, now 3 | Dairy |
| | 5 | Dry stock (sheep and beef) |
| | 10 | Forestry |
| | 5 | Other (deer) |
| *Gisborne District Council*[1] | *3* | *Most sites* |
| | *5* | *Conservation* |
| Hawke's Bay Regional Council | 3 | Cropping |
| | 5 | Remainder |
| Horizons Regional Council | 5 | All |
| Taranaki Regional Council | 5 | All |
| Greater Wellington Regional Council | 5 | Horticulture |
| | 3 | Cropping/arable/market garden |
| | 3 | Dairy |
| | 5 | Dry stock |
| | 5 | Forestry |
| | 10 | Indigenous vegetation |
| Tasman District Council | 10 | All |
| Marlborough District Council | 5 | All |
| Environment Canterbury | 8 – generally length of cropping cycle | All |
| Environment Southland | None yet | All |

[1] Planned resampling as sampling is yet to commence

#### 6.3.1 Sample analysis

Summaries of the analyses undertaken on collected samples are shown in Tables 10 and 11, with detailed data in the C*ollated_analyte, lab, metadata_Spreadsheet.xls* file. Because the basic soil quality chemistry analyses were so variable between councils and over time, only the laboratories where analyses were undertaken are provided in Table 10. However, in brief, pH and total C were always analysed, total N, AMN and Olsen P were most typically analysed, followed by $NO_3$, $NH_4$ (this is also part of the determination of AMN), and CEC (typically with exchangeable cations / base saturation). Most soil quality chemical analyses were undertaken by Landcare Research, with a smaller number undertaken by Hill Laboratories – primarily in recent years. Analyses for hot water carbon and hot water nitrogen were undertaken by AgResearch.

For the physical soil attributes, bulk density and macroporosity analyses were undertaken by all but one council, with analyses typically undertaken by Landcare Research. Aggregate stability was also undertaken by all councils except one, with analyses primarily undertaken by Plant & Food. Aggregate stability was most typically undertaken on cropping sites, when specified. Hot-water-extractable C and N (HWC, HWN) were undertaken by AgResearch.

For trace element analyses, the heavy metal suite (As, Cd, Cd, Cu, Pb, Ni, Zn) was most typically analysed, with Hg and F common additional elements (Table 11). One council analysed for Cd only, while another analysed for Cd and Zn only. Three councils undertook analysis of an extended suite of trace elements, with up to 38 elements analysed.

A number of comparative analyses have been undertaken by different councils including:

- macropores at –10 and –5 kPa, Olsen P by gravimetric and volumetric methods, irrigated and not irrigated, fertilised and not fertilised, organic farming and conventional, no-till arable and conventional, forest to pasture and remaining forest (by WRC)
- inter-row comparison for orchard/vineyard sites (by HBRC and MLDC)
- comparisons for gravimetric and volumetric Olsen P methods by GWRC and ES
- samples under trees next to the paddock by HRC.

Seven councils (AC, WRC, HBRC, GWRC, HRC, TRC, Ecan) currently archive samples. Samples for archiving are sieved dried samples returned from the laboratory after analyses. One council found that previously stored archived samples had been discarded recently, but archived samples will be stored for future samplings. Gisborne District Council is planning to archive samples.

**Table 10** Overview of laboratories used to undertake different measures for soil quality monitoring

| Council | Soil quality chemistry laboratory | Additional soil quality chemistry | Laboratory | Physical soil attributes | Physical soil attributes laboratory | Aggregate stability | Aggregate stability laboratory |
|---|---|---|---|---|---|---|---|
| NRC | Landcare Research | | | | | | |
| ARC | Landcare Research | | | IWC, BD, TP, PD, MP | Landcare Research | Hort sites only | Landcare Research |
| Waikato | Landcare Research | HWC, HWN, 15N | AgResearch, Waikato Uni | BD, MP | Landcare Research | Cropping sites, forest converted to pasture | Plant & Food |
| BoP | Landcare Research, Hill Laboratories (2015) | | | IWC, BD, TP, PD, MP | Landcare Research | 1999, 2000 | Unknown |
| HBRC | Hill Laboratories | | | BD, PD, TP, MP, FC, AWC | Landcare Research | Aggregate stability | Landcare Research |
| HRC | Landcare Research | HWC, HWN | AgResearch | WC, BD, PD, TP, MP-5, AirFP-10, VWC5Pa, VWC10kPa, VWC100kPa, VWC1500kPa, RAW, TAW | Landcare Research | Aggregate stability | Plant & Food |
| TRC | Landcare Research | | | BD, MP | Landcare Research | No | |
| GWRC | Landcare Research, Hill Laboratories | HWC, HWN | AgResearch | BD, MP (−10 kPa called air-filled porosity by LR); pores at −5 kPa, TP, PD, vol. water content | Landcare Research | Aggregate stability (typically cropping/hort. sites, all sites one year) | Plant & Food |
| TDC | Landcare Research | | | BD, MP | Landcare Research | Yes | Plant & Food |
| MDC | Landcare Research, Hill Laboratories | | | BD, MP | Landcare Research | Yes | Plant & Food |
| Ecan | Plant & Food, Landcare Research, ARL | | | BD, MP | AgResearch | Yes | Plant & Food |
| ES | Landcare Research | | Landcare Research | BD, MP, PD, TP | Landcare Research | Yes | Plant & Food |

BD–bulk density, MP–macroporosity, PD – particle density, TP – total porosity, FC–field capacity, VWC – volumetric water content, RAW–, TAW–

**Table 11** Overview of trace element analyses and laboratories used by different councils

| Council | Trace elements | Additional tests | Laboratory |
|---|---|---|---|
| NRC | HM, Co | | Landcare Research |
| ARC | Extended suite, including HM | | Hill Laboratories, Watercare |
| WRC | Extended suite including HM, U, Hg, F | XRF | Hill Laboratories, Waikato University |
| BoPRC | 33 elements, including HM suite trace level and Hg (2015) and F (2010) | OCPs, PAHs | Hill Laboratories |
| HBRC | HM, F, U | OCPs | Hill Laboratories |
| HRC | HM | | Hill Laboratories |
| TRC | Cd, Zn | | Landcare Research |
| GWRC | HM, F, U, Fe, Mn | | Hill Laboratories |
| TDC | HM | | Hill Laboratories |
| MLDC | HM, Hg, F | | Hill Laboratories |
| Ecan | Cd, HM (selected years) | | Hill Laboratories, ARL (2003) |
| ES | HM | | Hill Laboratories |

HM = heavy metal suite: As, Cd, Cr, Cu, Pb, Ni, Zn

## 6.4 Data analysis management systems and procedures

### 6.4.1 Data analysis

Most councils aimed to report differences between land use, change over time and comparison with guideline or target values. Most undertook basic statistics (e.g. mean, median, range) on data for routine annual reporting. Where trace element data are available, concentrations less than the detection limit (DL) could be omitted or reported as 1/2DL. Only one council reported handling outliers, which involved removal from the data set if there was a valid reason. Eight councils report macroporosity data as the average of three replicate samples; no response was received from the remaining councils.

Six councils reported using bulk-density data in the reporting of results, including for total C and total N, AMN, Olsen P, any volumetric comparisons, porosity calculations, and other soil physical data. Only one council reported presenting both raw site data and area-weighted data. Seven councils indicated that they undertook more statistical analyses for more in-depth reporting, with ANOVA (including repeated measures) most commonly performed (four councils). One council used paired *t*-test to test changes over time, one council used spline regression to assess, while another council assessed the interaction between land use and soil using hierarchical / mixed model approaches.

*Soil guideline and target values*

Different source documents are used for comparing soil quality and trace element results with different soil guideline values (Tables 12, 13). It is useful to be mindful of the terminology used for these soil guideline values. Specifically, the guidelines developed for soil quality parameters are values that are desirable to have (i.e. they are target values). In contrast, soil guideline values for trace elements (with the exception of those signalling deficiencies) represent concentrations above which negative effects may occur, and therefore they are not concentrations that are desirable to have (i.e. they are *not* target values).

For soil quality parameters, the sources vary according to time since publication, and some have been updated with changes to target values while others have not. We consider this a critical area that should be addressed as soon as possible to standardise target value reporting across all regions. For national reporting (e.g. contributions to Environment Aotearoa 2015), the same target values were applied across all regions (although this comparison was not included in the final report), but there have been some differences in how the data were reported in comparison to regional reporting. Resolution of these differences will be discussed in an EMaR meeting scheduled for July 2017.

For trace elements, the majority of councils used the NZWWA (2003) guidelines for land application of biosolids. This document has nominally now been superseded by *Guidelines for the Beneficial Use of Biowastes in New Zealand*, although this has yet to be finalised. However, these new guidelines do not include soil limits for contaminants. Instead, the draft document directs users to draft ecological soil guideline values (Eco-SGVs), which were recently developed through an Envirolink tools project (Cavanagh & Munir 2016). Three councils report already using the draft Eco-SGVs, although they have no formal status (Cavanagh 2016). Five councils compare Cd results to the Tiered Fertiliser Management System (MPI 2011). Only one council also assessed trace element concentrations for potential deficiencies (using Alloway 2008). Only one council appears to also consider human health impacts, through comparison of concentrations with MfE 2011.

**Table 12** Summary of source documents for comparing soil quality results with target values

| Council | LMF 2009 | SINDI database | Sparling et al. 2003, 2008 | Mackay et al. 2013 | Other |
|---|---|---|---|---|---|
| **NRC** | | | | | |
| **AC** | | | Yes for all | | Yes for all (Taylor 2011) |
| **WRC** | Yes (pH, total C, total N, mineralisable N, Olsen P, bulk density, macroporosity) | | | Yes (mineralisable N, Olsen P, macroporosity, aggregate stability) | |
| **BoPRC** | | | Yes (pH, total C, total N, mineralisable N, Olsen P, bulk density, macroporosity) | | |
| **HBRC** | Yes (pH, total C, total N, mineralisable N, Olsen P, bulk density and macroporosity) | Yes (pH, total C, total N, mineralisable N, Olsen P, bulk density and macroporosity) | Yes (pH, total C, total N, mineralisable N, Olsen P, bulk density and macroporosity) | Yes (pH, total C, total N, mineralisable N, Olsen P, bulk density and macroporosity) | |
| **HRC** | Yes (pH, total C, total N, mineralisable N, bulk density, macroporosity, aggregate stability) | | | Yes (Olsen P) | 80 for very high Olson P |
| **TRC** | | | Yes (pH, total C, total N, mineralisable N, Olsen P, bulk density, macroporosity and aggregate stability) | | |
| **GWRC** | Yes (pH, total C, total N, bulk density and macroporosity) | No | No | Yes, or Taylor's unpublished document/pers. com. (mineralisable N); yes (Olsen P); yes more recently (macroporosity) | Discussion with LMF colleagues (macroporosity); Matt Taylor pers. com. based on info. from Plant & Food (aggregate stability) |
| **TDC** | Yes (pH, total C, total N, mineralisable N, Olsen P, bulk density, macroporosity and aggregate stability) | | | | |

| | | | | |
|---|---|---|---|---|
| **MLDC** | | Yes (pH, total C, total N, mineralisable N, macroporosity | Yes (macroporosity) | Olsen P (Taylor 2011) |
| **Ecan** | | | Yes (pH, total C, total N, mineralisable N, Olsen P, bulk density, macroporosity, aggregate stability) | |
| **ES** | Yes (pH, total C, total N, mineralisable N, Olsen P, bulk density, macroporosity) | | | |

**Table 13** Source documents used to compare trace element concentrations from soil quality monitoring.

| Council | NZWWA (2003) Biosolids Guidelines | Tiered Fertiliser Management System (Cd only) | Ecological soil guideline values (Envirolink Tools project) | Alloway 2008 | Other (specify) |
|---|---|---|---|---|---|
| **WRC** | Yes (As, Cr, Cu, Pb, Ni, Zn) | Yes (Cd) | Yes (As, Cd, Cr, Cu, Pb, Ni, Zn) | Yes (Cu, Zn) | |
| **BoPRC** | Yes (As, Cd, Cr, Cu, Pb, Ni, Zn) | | | | |
| **HBRC** | Yes (As, Cd, Cr, Cu, Pb, Ni, Zn) | | | | CCME (Cd) MfE (all) |
| **TRC** | Yes (As, Cd, Cr, Cu, Pb, Ni, Zn) | Cd | | | |
| **HRC** | Yes (As, Cr, Cu, Pb, Ni, Zn) | Yes (Cd) | | | |
| **GWRC** | Yes (As, Cr, Cu, Pb, Ni, Zn); No (Cd) | Yes (Cd) | Yes (As, Cd, Cr, Cu, Pb, Ni, Zn) | Cu | Drewry et al. 2017 for F |
| **TDC** | | | Yes (As, Cd, Cr, Cu, Pb, Ni and Zn) | | |
| **MLDC** | Yes (As, Cd, Cr, Cu, Pb, Ni, Zn) | | | | |
| **Ecan** | | Cd | | | |

### 6.4.2 Data management

Data were mostly stored as Excel spreadsheets (ARC, WRC, BoPRC, HBRC, HRC, TDC, MLDC, Southland − for soil physics), with one council indicating that laboratory results were also stored in document systems, currently Sharepoint. Some councils also use, or are planning to use, databases. Specifically, Auckland Council uses the council database, and three councils use Hilltop (Tasman, Marlborough, Southland – soil chemistry only), although one council indicated Hilltop didn't work well with soil data. Environment Canterbury use Microsoft Access, while Bay of Plenty Regional Council is planning to integrate data into the Aquarius database this year.

One council did not respond. One council indicated that analyte names are used to create additional fields in their database. One council reported using the LAB system for the capture of laboratory results. Two councils indicated that the inclusion of additional fields for soil quality in databases is currently underway.

Seven councils use experienced staff to manually check data, while two councils indicated no process was used, and five didn't respond. Manual checking included visual assessment for outliers and checking for data entry errors. One council has partially scripted the transfer of laboratory results provided as a spreadsheet into their database to remove the chances of human error.

Six councils indicated external consultants were used to assist with analysis (primarily) and reporting. One council indicated that they had found external consultants poor.

#### 6.4.3 Reporting

Reporting was most often directed to a mixture of general public and the science community. All but one council indicated that technical reports are produced, although the frequency varies. Some are produced annually (e.g. for a specific land use), while others (typically more in-depth reports) are produced on a 5- (four councils) to 10-year basis. Two councils reported producing fact sheets or report cards on the results (eight councils indicated they did not, and two councils did not respond), while seven councils reported online, typically by uploading pdfs of reports. Four councils indicated that scientific publications were also produced, with other miscellaneous forms of reporting including presentations (general public and science community) and posters.

Seven councils reported providing results to the landholder in the form of a copy of a relevant report, individual results or summary of results. One council reported communicating with the landholder via phone, although it is unclear whether that is to communicate results or to obtain access or site information. Some councils indicated that limited advice is provided to landholders about the results and/or they are directed to SINDI for interpretation. Four councils indicated that no advice is provided.

# 7 High-level statistical review and SWOT analysis

## 7.1 Statistical review

Soil health has been identified by the Ministry for the Environment for development as a Tier 1 statistic to be reported on a 5-yearly basis and is currently considered as a case study, indicating further development is required. Tier 1 statistics are intended to be relevant (critical to essential decision-making and of high public interest), authoritative and trustworthy, provide long-term continuity of statistical information, and enable international comparability.  A Tier 1 statistic can be either a single statistic or a specified set of statistics. The requirements for a Tier 1 statistic are outlined in Statistics New Zealand 2007 and include 10 principles and six protocols containing a varying number of 'elements' to be followed to generate a Tier 1 statistic (Table 14).

**Table 14** Principles and protocols to generate a Tier 1 statistics

| Principles | Protocols |
|---|---|
| **Relevance – official statistics produced by government agencies are relevant to current and prospective user requirements, in government and in the wider community** | Quality – 8 elements |
| **Integrity – official statistics gain public trust by being produced and released using objective and transparent methods** | Frameworks, standards and classification – 4 elements |
| **Quality – official statistics are produced using sound statistical methodology, relevant and reliable data sources, and are appropriate for the purpose** | Respondent management – 8 elements |
| **Coherence – the value of statistical data is maximised through the use of common frameworks, standards and classifications** | Confidentiality, privacy and security – 7 elements |
| **Accessibility – access to official statistics is equal and open** | Release practices – 8 elements |
| **Efficiency – official statistics agencies strive to be efficient and provide value for money** | Management documentation and preservation of statistical records – 5 elements |
| **Protecting respondent information – respondents' rights to privacy and confidentiality are respected and their information is stored securely** | |
| **Minimising respondent load – the costs of compliance are kept to an acceptable level and data are collected only when the expected benefits of a statistical survey exceed the imposition on providers** | |
| **Maximising existing data – maximise the use and value of existing data by integrating or aligning available statistics and administrative sources** | |
| **International participation – official statistics agencies make use of and contribute to international statistical developments** | |

Many of these principles and protocols relate to the surrounding 'framework' of data management and processes, and as such are largely beyond the scope of the current review.

Regardless, it is pertinent to bear these principles in mind as pragmatic considerations for the durability of a soil health statistics, particularly with respect to minimising respondent load and protecting respondent information (in this case, the landholder's), and enabling international participation. (In this respect it is worthwhile noting that the environmental sustainability of the Canadian agriculture programme was largely developed to enable such a comparison). The current review facilitates consideration of how existing data can be maximised (Principle 9) by undertaking a stocktake of existing data and data management systems. The solutions for maximising existing data, and what ultimately constitutes the Tier 1 statistic, are intended to come out of EMaR and NEMS processes (along with other considerations to develop the Tier 1 statistic).

Nonetheless, there are technical components, particularly related to Protocol 1 (Quality), that warrant consideration and further discussion here. The key ones are relevance (element 4), accuracy (element 5), consistency (element 7) and interpretability (element 8) in Protocol 1 (Quality). Relevance is the degree to which the statistical product meets user needs in coverage, content and detail (Statistics New Zealand 2007). Content and detail, and interpretability arguably falls out of the detailed analysis of the data and also links to ongoing research (see also section 7.3). As such content and detail component of Relevance is not discussed further here.

The coverage component of relevance will be discussed further below – particularly as it relates to determining the representativeness of the data collected. Accuracy includes consideration of the analytical methods used to provide the data, and is linked to consistency of methodologies. Consistency is a critical consideration for the current work. This includes consistency in reporting specific identified parameters by all regional and unitary councils, and consistency in methods of analysis (at least with regard to ensuring the comparability of results if different methods are used).

At a different level there is ensuring consistency in data analysis. However, probably the biggest challenge lies with ensuring consistency in land-use classification. As noted in Statistics New Zealand 2007, 'Consistent classifications allow users to easily define and identify what has been collected and what the data represent'. As consistency in land-use classification is critical to the discussion on coverage and representativeness, this is discussed first.

### 7.1.1 Land-use classification

As noted earlier, land use is inconsistently classified by different councils. This in turn can confound interpretation of the data. Inconsistent classification of land use is not a new issue, and various efforts have been directed towards improving consistency or providing systems that allow flexibility in classification. However, ideally a classification system can be developed such that the same system can be used, at different levels of detail, to provide the desired information in a consistent fashion across New Zealand, enabling greater integration and interpretation of data collected for different purposes (e.g. trace element concentration and soil biodiversity). While detailed information about a site should be captured to enable different categories to be developed to meet user purposes, there remains a need to develop higher-level land-use categories to facilitate the consistent capture of data across regions, and in this case facilitate national reporting.

While LMF (2009) presented a hierarchical land-use classification to attempt to facilitate greater consistency, this has not been achieved. Table 15 presents a land-use categorisation in relation to potential useful descriptors for soil quality sites. This builds upon the classification in LMF 2009 and is based on experience obtained in assessing cadmium concentrations in New Zealand soils (Cavanagh 2014), determining the background concentrations of trace elements (Envirolink Tools project), and collating regional council soil quality data information. It includes consideration of classification systems used in the LCDB, Ministry for the Environment carbon monitoring (LUCAS), and the New Zealand Standard Industrial Output Categories used by Stats NZ.

The classification is focused on delineating agricultural land uses that have similar management aspects (e.g. fertiliser application, cultivation frequency, types of pesticides and veterinary chemicals used). While Table 15 presents dairy and dry stock (sheep/beef/deer) as separate categories, further consideration should be given to exactly what features of these systems are important to delineate. In other words, are these categories being primarily used as surrogates for intensity of inputs, or are there other reasons to justify the delineation, such as public interest in the effects of dairy? LMF (2009) distinguished between intensive and extensive pasture based on differences in LCDB grassland coverage classes, but this hasn’t equated to ‘on the ground’ assessments of intensive and extensive pasture, as there is no agreed definition of what constitutes intensive or extensive systems for soil quality purposes.

For comparison, the original 500 Soils programme used the categories of indigenous, forestry, dairy, dry stock, arable cropping,  and horticulture, while recent reporting for the Ministry for the Environment uses  the categories crop/horticulture, dairy, dry stock and forestry.

**Table 15** Potential land-use categorisation for soil quality monitoring

| Land-use category 1 | Land-use category 2 | Land-use category 3 | Comment on land use |
|---|---|---|---|
| Dairy | Dairy | Dairy | Includes organic dairy, irrigated and non-irrigated dairy. Needs to be clear whether this includes milking cows only. Needs to also consider whether a combined pastoral classification, perhaps based on input intensity, is more relevant. |
| Sheep/beef/deer | Sheep and beef<br><br>Deer<br>Other | Sheep<br>Beef<br>Deer<br>Other | Includes sheep and beef, deer, goats, and is likely to be a mix of intensive and extensive systems. Ideally intensive and extensive systems could be identified with extensive (low-input) systems including lifestyle blocks. Needs to be clear as to whether this includes dairy run-off (i.e. dry stock). Needs to also consider whether a combined pastoral classification, perhaps based on input intensity, is more relevant. |
| Pasture | Unspecified pasture, pasture seed crops | Unspecified pasture, pasture seed crops | Only if needed, and land use cannot be categorised as above. Needs to also consider whether a combined pastoral classification, perhaps based on input intensity, is more relevant. |
| Vegetable cropping | Horticulture | Crop type | Market gardens, vegetable crops |
| Arable cropping | Arable cropping | Crop type | Includes grain crops, hay, fodder crops |
| Perennial crop | Orchard<br>Vineyard | Crop type | Stonefruit, berry fruit, kiwifruit<br>Grapes |
| Forestry | Plantation | Tree type | |
| Indigenous | Indigenous forest, native scrub, reserves in non-urban areas, native tussock not used for grazing | Specify | Greater delineation could be used to define this category |
| Urban | Parks and reserves<br>Other | Parks and reserves<br>Specify | |
| Other | | Specify | |

For trace elements, and arguably other soil properties, land-use history for a given piece of land may be a significant factor influencing concentrations at a given point of time, and may be more significant than the current land use. However, current land use is most often used for grouping the results of soil analyses (e.g. Cavanagh 2014, soil quality reporting), because sufficient information to provide alternative classifications typically isn't available. An exception is the classification of agricultural land for soil quality data collected in Canterbury, which includes classifications based on the duration of cropping or pastoral use (Lawrence-Smith & Tregurtha 2013). This is a source of error in interpreting the influence of land use on trace element concentrations, and potentially other soil properties, over time.

It should also be noted that land-use classification based on land use at the time of sampling can be problematic. For example, a site on which grain crops are present at the time of sampling could be classified as an arable site, although it may be more appropriately classified as dry stock, dairy (or, ideally, a mixed cropping system); a site on which kale is grown as a fodder crop could be classified as a horticultural site, although it is probably more appropriately classified as dry stock or dairy. These 'misclassifications' appear to relate primarily to dry stock or dairy systems, and a suggested 'farm system' classification is given in Table 16. Depending on the conversation about the relative importance of distinguishing between dairy and dry stock vs intensive and extensive pasture, these categories could be modified accordingly.

Further discussion is required on whether a minimum proportion of the farm or frequency of other crops needs to be specified to distinguish between pastoral and mixed cropping, or between different mixed cropping farms. It is anticipated that the farm system for non-livestock farms would be represented by the observed land use at the time of sampling, although this should be verified.

However, we recognise that land use at the time of sampling is needed to be able to appropriately assess soil properties against specific target values. Thus, the optimal recording of land use is both the farm system and the land use at the time of sampling.

**Table 16** Potential farm system categorisation for soil quality sites on dry stock and dairy farms[1]

| Farm system | Description |
|---|---|
| **Dry stock – pastoral** | Pastoral farm system. |
| **Dry stock – mixed cropping** | Pasture and feed (grain, forage) crops (including dairy support) grown on a rotational basis. (Is there a need to consider frequency of crop rotation / pasture renewal or proportion of farm used for other crops to further delineate?) |
| **Dairy – pastoral** | Pastoral farm system |
| **Dairy – mixed cropping** | Pasture and feed crops grown on a rotational basis. (Is there a need to consider frequency of crop rotation / pasture renewal or proportion of farm used for other crops to further delineate?) |

[1] It is anticipated that by considering farm system, sites previously identified as pasture would also be able to be assigned to dry stock or dairy and thus improve land-use categorisation

### *Intensive versus extensive pastoral systems*

An alternative approach to identifying land use, and to provide a basis for determining intensive vs extensive systems, was constructed based on the potential use of phosphate fertilisers on livestock farms (P-fertiliser is the principle source of Cd, U and F accumulation in New Zealand soils) by Manderson et al. (2017). This used a potential P-fertiliser demand index (PFDI), which calculates:

- P-development requirements for a given farm according to soil types and minimum optimal Olsen P levels
- P-maintenance requirements according to current stocking rate, estimated milk solids production (dairy) and soil types.

Actual Olsen P levels will vary widely between farms, and in many cases P-development is likely to have been achieved on intensive farms decades ago. For this reason an index was used as an indicator of potential P-fertiliser demand, and we acknowledge that this will in no way come close to representing actual P-fertiliser use over the years.

The method for calculating the PFDI is summarised in Figure 2 and described in detail in Manderson et al. 2017. The method draws on values recommended for fertiliser use on New Zealand dairy farms (Roberts & Morton 1999) and sheep/beef farms (Morton et al. 1994). Required spatial inputs include the Agribase (stocking rate and farm type), Livestock Improvement Corporation (LIC) dairy statistics by district (LIC 2014), LCDB4, and soil information from the Fundamental Soils Layers (FSLs) (as this has national coverage while S-Map currently does not).

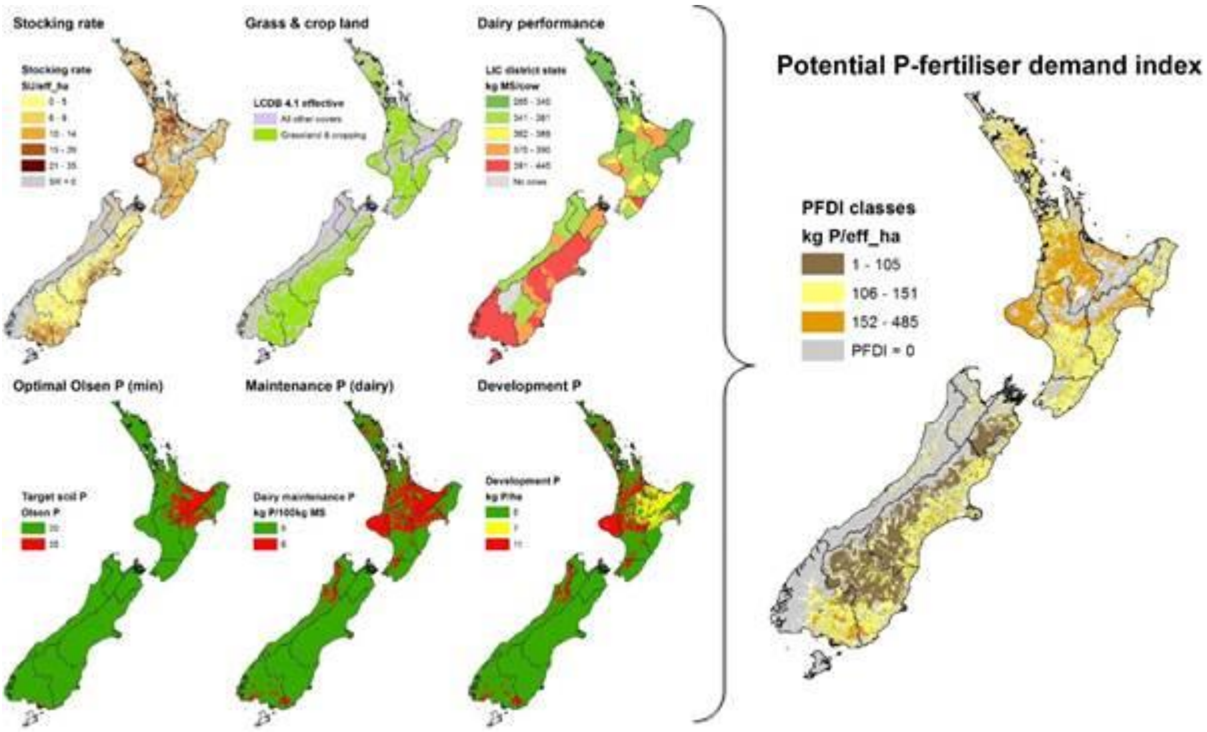


**Figure 2** Overview of the PFDI method.

For pastoral systems (i.e. those identified by the intersection of LCDB grassland covers with Agribase livestock types), four levels of P-fertiliser demand index were identified (Table 17). Identification of sites located within these areas would provide an independent classification of intensive (high input – Grass_3 classification, potentially Grass_2) vs extensive (low input – other grass classifications) systems.

**Table 17** Classification of grassland systems according to potential phosphate fertiliser demand

| Tier 1 | Tier 2 | Description |
|---|---|---|
| Grassland | Grass_0 | Grassland where the PFDI = 0 (mostly unfarmed grassland) |
| | Grass_1 | Pastoral grassland with a low PFDI (e.g. South Island high country grassland) |
| | Grass_2 | Pastoral grassland with a moderate PFDI |
| | Grass_3 | Pastoral grassland with a high PFDI (mostly dairy in ash/pumice areas) |

This approach can be extended to non-livestock farms, including vineyards (grapes), orchards (including nuts), herb farms, nurseries and flowers, and all forms of vegetable growing can be captured, but they are less of a focus in the current work. A summary of the combined Agribase/LCDB classes, and their relationship to the land-use categorisation used in Table 15 are shown in Table 18.

The Agribase database also identifies 'enterprises' on farms, which are effectively different land uses on a farm of a different type (e.g. a dairy farm on which arable crops are also grown would be considered to have an arable enterprise). This information could be useful to provide a cross-check on the farm system within which specific soil quality monitoring sites are located.

**Table 18** Horticultural and non-horticultural classification based on a matrix classification between relevant LCDB and relevant Agribase enterprises, in relation to land-use categories specified in the table

| Agribase/LCDB class | Definition | Proposed classification |
|---|---|---|
| Arable | Land on arable and pastoral farms used for annual cropping (grain, fodder, etc.) | Cropping |
| Cropping | Land on cropping farms used for annual cropping of veges, etc. | Vegetable cropping |
| Orchard | Land on orchards used for perennial crops (apples, kiwifruit, etc.) | Perennial cropping |
| Viticulture | Land on vineyards used for perennial crops (grapes for wine) | Perennial cropping |
| Pastoral | | Dairy, sheep/beef/deer, pasture |
| Other uses | | Other |

This alternative land-use classification was developed as a first cut for assessing Cd accumulation risk, and further work is recommended before implementation and use, including for more general soil quality work. This includes additional investigation into appropriate thresholds. (For example, it may be that just two levels of P-fertiliser demand are needed to distinguish between intensive and extensive systems.) Other recommendations for review are as outlined by Manderson et al. (2017). However, their classification of 'ash' soils based on high P-retention includes some soils that have not formed from an ash parent material, so it may be pertinent to look at P-development and P-maintenance using P-retention relationships alone. Likewise, use of the S-map database would be an improvement over the FSLs.

PFDI also needs to be distributed within farms to match the scale of horticultural classification. (As it stands, there will be large farms with low PFDI that will include areas of far more intensively used land.) Spatially inheriting farm types from the surrounding locale was assigned on a dominant area basis (e.g. if the 'missing' farm is surrounded dairy farms, the missing farm is most likely to be a dairy farm). In this case, we throw a buffer around the missing farm (e.g. of 1 km), then calculate the dominant land use by area that falls within that buffer); in some cases a dominant count basis would have been more suitable (e.g.

lifestyle blocks). There remains an opportunity to add other data sets as a better means of updating missing parcels such as lifestyle blocks.

### 7.1.2 Coverage and representativeness

A preliminary assessment of the coverage and representativeness of current soil quality monitoring sites was made on the basis of region, land use and soil order. To do this, regional council data previously provided to Landcare Research for the determination of background concentrations of trace elements was cross-checked with sampling inventories provided by the current survey to generate a spreadsheet that captures all sites indicated to be used for current soil quality monitoring. This data included sites that had been resampled over time and which were However, as the current survey did not capture the specific location of the soil quality monitoring sites, sites that were more recently established (i.e. 2015, 2016) and for Horizons Regional Council were excluded from the analysis. Anthropic soils are also removed, as there are only a few of them and they do not fit within the scope of this task. This resulted in 1,187 sites in this data set, located as shown in Figure 3, which compares to a total of approximately 1,143 current sites based on the current survey. The greater number of sites in Figure 3 is due to the retention of resampled sites which differed in location by more than 10m.

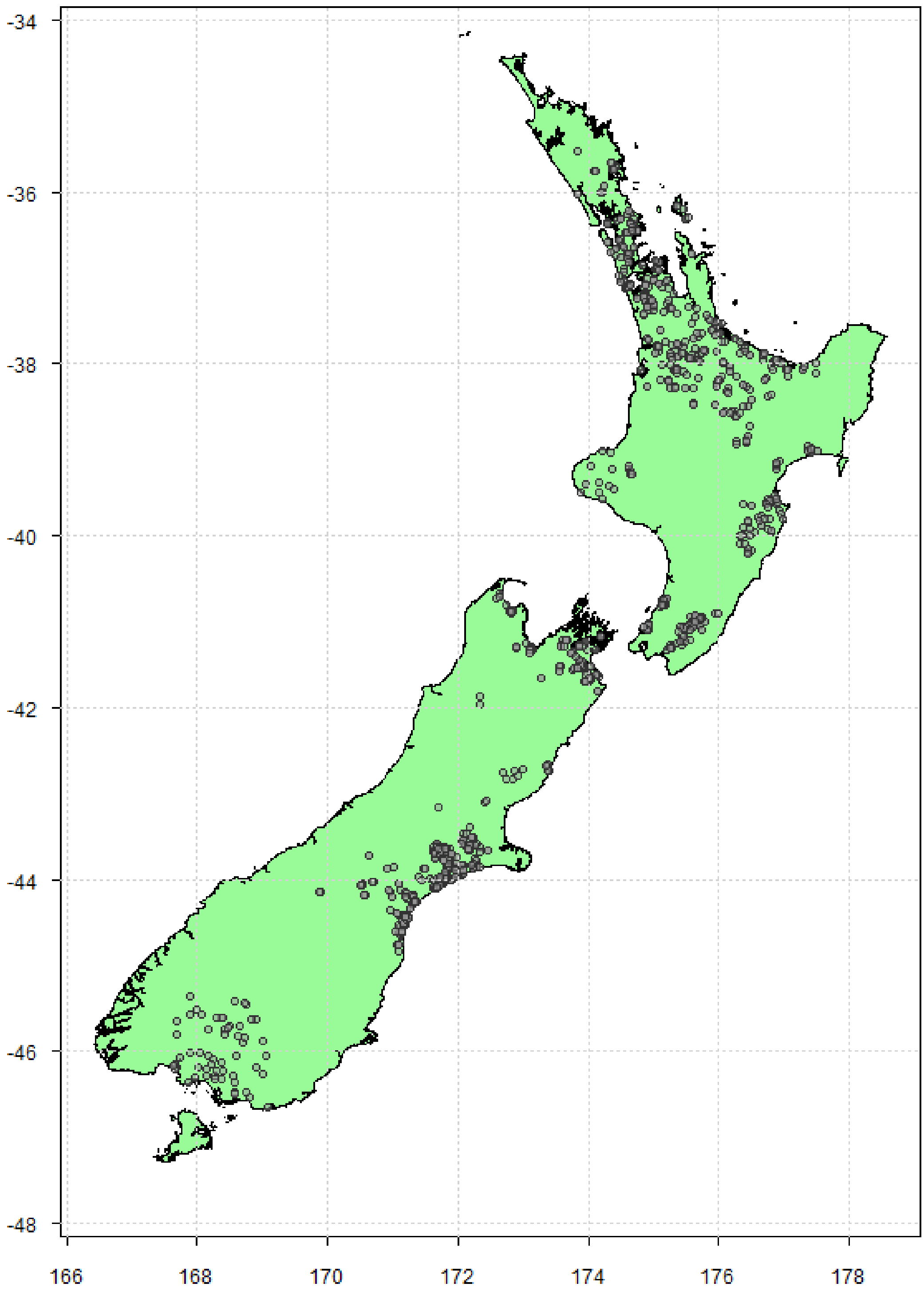


**Figure 3** Location map of the samples used to determine representativeness.

In addition to the basic site data (land use, location), information was extracted on land use (land cover), soil order and region name from external data sets. The soil quality data do have fields corresponding to land use, soil order and region, but the external data enables an assessment based on relative area. Representativeness was considered on the basis of classification

*Definition*

The representativeness of a data sample is defined as how accurately the data reflect the universe of all possible relevant data. For instance, if a soil sample is intended to cover all possible soil orders of New Zealand, then a representative sample would be expected to contain sufficient samples for each soil order commensurate with the area that each soil order occupies. Thus, if a particular soil order was 5% of the total land area of New Zealand, then a representative sample containing that soil order might reasonably be expected to be approximately 5% of the total number of samples.

If the data sample contains only one variable over which representativeness is to be assessed, then the problem of selecting and checking this requirement is straightforward − if not necessarily simple − since (intuitively) the requirement is for the data to be 'spread' over the range of the variable, commensurate with the areal coverage of each variable. Representativeness is often assessed with respect to several variables simultaneously, such as soil order, region, and slope class, or for individual analytes. However, for simplicity, this is not considered here.

An additional complication in the assessment of representativeness is that the conceptual procedure for determining whether a data sample covers the whole range of some variable requires that the whole range of that variable is known. For instance, if representativeness is required in a data sample for soil order over New Zealand, then what is needed is the coverage of all soil orders over the country. In practice this information is patchy: some regions of the country are covered by S-map and detailed information on soil order is known, but for other regions soil order information may only be available through the FSL. The total land area associated with (say) semi-arid soils must necessarily be taken from a combination of S-map and FSL-estimated land area, and there will be a component of uncertainty in this assessment as a result of the relatively coarse nature of the FSL, which will vary from one soil order to another.

For valid statistical analysis, however, we would not necessarily need to have perfect representativeness across all soil order and/or land-use combinations. A minimum number of sites is needed to provide sufficient statistical power to determine differences. Therefore, a relatively rare element (assuming that element is considered important enough to be sampled) may need to be over-represented in the data set. On the other hand, elements that make up a large area (for instance Brown Soils) can be somewhat under-represented, as there will be enough samples to provide sufficient statistical power.

One implicit requirement for representativeness is that a data sample should be taken from the widest spatial coverage available, rather than repeated sampling in one region. This is particularly in relation to soil order/land-use combinations that might extend across different climatic regions of New Zealand. There are two main reasons for this.

- Samples that are spatially spread are more likely to yield physical parameters that represent the true variation that one might expect to see in environmental data.
- Samples that are taken close together tend to yield physical parameters with a degree of inherent correlation, due to the physical processes involved in their formation. The

spatial distance over which this spatial correlation exists depends on the physical parameter involved, but could be as large as tens of kilometres.

*Data sources*

In this document, representativeness is considered for the soil quality data set for land use, region and soil order. Each of these terms is used in an everyday sense as well as having a precise technical meaning, so it is important to describe here exactly how the data were defined.

A region is here taken to mean a regional authority, defined by spatial coverage of New Zealand regions sourced from the Land Resource Information Systems portal.[6] This coverage extends beyond the coastline, so to maintain a consistent estimate of land area the coverage of each region was clipped to the coastline boundary.

Soil order is the top level of the New Zealand Soil Classification (NZSC), and is not available for all regions of New Zealand in a consistent scale and quality. The approach taken here was to use the soil order of the dominant soil in the top layer of the soil where detailed S-map soil information was available. Where S-map coverage was not available, the soil order was extracted from the New Zealand Fundamental Soils Layers (FSL) instead. This approach provides full coverage over all New Zealand, but for areas only covered by the FSL the result is expected to give higher uncertainty.

Land use was based on both the classification provided in the soil quality data, categorised as shown in Table 15 as well as using land cover classes in LCDB. It was also intended to use land use based on that determined through the phosphorus fertiliser demand index (PFDI) developed by Manderson et al. (2017). However, technical challenges prevented this.

*LCDB*

The Land Cover Data Base (LCDB)[7] provides a rich set of nested land-use classes for four dates (1996, 2001, 2008 and 2012). For the purposes of determining representativeness, the LCDB classes are aggregated according to the scheme in Table 19. It is important to note that the 'Other' class is intended to represent land-use classes that were excluded from consideration for the representativeness assessment, rather than as a grouping of similar land-use classes.

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[6] https://lris.scinfo.org.nz/layer/306-nz-regional-councils-2008

[7] https://lris.scinfo.org.nz/layer/423-lcdb-v41-land-cover-database-version-41-mainland-new-zealand/

**Table** 19 Aggregation of LCDB land cover classes for determining representativeness

| LCDB class | Aggregated class |
|---|---|
| High Producing Exotic Grassland | Pasture |
| Indigenous Forest | Native |
| Tall Tussock Grassland | Pasture |
| Exotic Forest | Forest |
| Low Producing Grassland | Pasture |
| Mānuka and/or Kānuka | Native |
| Gravel or Rock | Other |
| Broadleaved Indigenous Hardwoods | Native |
| Sub Alpine Shrubland | Native |
| Short-rotation Cropland | Cropping |
| Lake or Pond | Other |
| Alpine Grass / Herbfield | Other |
| Forest – Harvested | Forest |
| Gorse and/or Broom | Pasture |
| Built-up Area (settlement) | Other |
| Depleted Grassland | Pasture |
| Herbaceous Freshwater Vegetation | Other |
| Matagouri or Grey Scrub | Pasture |
| Permanent Snow and Ice | Other |
| Orchard, Vineyard or Other Perennial Crop | Hort |
| Deciduous Hardwoods | Forestry |
| Estuarine Open Water | Other |
| River | Other |
| Fernland | Native |
| Mixed Exotic Shrubland | Other |
| Sand or Gravel | Other |
| Urban Parkland / Open Space | Other |
| Mangrove | Other |
| Landslide | Other |
| Herbaceous Saline Vegetation | Other |
| Surface Mine or Dump | Other |
| Flaxland | Native |
| Transport Infrastructure | Other |

Aggregation of the LCDB land-use classes in the manner of Table 19 makes the interpretation of representativeness more straightforward. However, there are some soil quality samples that have a land-use assessment from the soil quality data set that differs from the LCDB class, and vice versa. Table 20 shows a cross-tabulation of soil quality land use class versus the simplified LCDB class. Some of this class contamination is benign, but some will be more serious as an issue and highlights the challenge faced in aligning different sources of information on land use. The greatest “misclassification” arises for dry-stock landuse with 82 sites being classified as cropping by LCDB.

**Table 20** Cross-tabulation of on-site classification with that determined from LCDB (number of sites)

| LandUse1 | Cropping | Forestry | Hort. | Native | Other | Pasture |
|---|---|---|---|---|---|---|
| Arable Cropping | 216 | 0 | 3 | 0 | 0 | 40 |
| Indigenous/background | 2 | 6 | 0 | 73 | 1 | 20 |
| Dairy | 2 | 1 | 2 | 2 | 2 | 238 |
| Drystock | 82 | 5 | 4 | 3 | 1 | 245 |
| Forestry | 1 | 70 | 0 | 0 | 0 | 16 |
| Horticulture Crop | 36 | 0 | 4 | 0 | 1 | 14 |
| Other | 0 | 0 | 1 | 0 | 1 | 1 |
| Pasture | 1 | 0 | 0 | 0 | 0 | 14 |
| Perennial Crop | 3 | 0 | 58 | 1 | 1 | 8 |
| Urban | 0 | 0 | 0 | 1 | 0 | 0 |

### *Representativeness by region*

For each region Table 21 gives the expected percentage of the soil quality samples (calculated from the region area, as a percentage of the total land area), as well as the actual percentage of soil quality samples calculated from the number of samples from that region as a percentage of the total land area). Clearly, for those regions that are not covered in the soil quality data set, the actual percentage is zero. For the regions that are covered, some are under-represented (e.g. Southland) while others are over-represented (e.g. Waikato), and others could arguably be seen as representative with respect to the region (e.g. Hawke's Bay).

**Table 21** Assessment of representativeness of current soil quality sites with respect to region: comparison of the expected % of samples for that region based on area and the actual % of samples[1]

| Region | Area $km^2$ | Expected % | Actual % |
|---|---|---|---|
| Northland | 12584 | 4.7 | 1.8 |
| Auckland | 5036 | 1.9 | 12.7 |
| Waikato | 24558 | 9.2 | 13.8 |
| Bay of Plenty | 12294 | 4.6 | 6.4 |
| Gisborne | 8386 | 3.1 | 0 |
| Hawke's Bay | 14211 | 5.3 | 5.6 |
| Taranaki | 7277 | 2.7 | 1.4 |
| Manawatu−Wanganui | 22271 | 8.3 | 0 |
| Wellington | 8130 | 3 | 9.5 |
| Tasman | 9670 | 3.6 | 3 |
| Nelson | 424 | 0.2 | 0 |
| Marlborough | 10514 | 3.9 | 7.8 |
| West Coast | 23381 | 8.7 | 0 |
| Canterbury | 45262 | 16.9 | 33.3 |
| Otago | 31873 | 11.9 | 0 |
| Southland | 31828 | 11.9 | 4.7 |

[1] Soil quality sites established from 2015, including those in Manawatu-Wanganui are not captured in this analysis

### *Representativeness by land use*

For each LCDB land cover class, Table 22 gives the expected and actual percentage of the soil quality samples, ranked by the expected percentage. Despite the limitations of the LCDB and its definition, the table does provide some useful information on representativeness. The pattern of the actual sample coverage follows the expected coverage, although there is strong evidence of over-sampling in ‘Cropping’ and ‘Hort.’, while under-sampling is evident in ‘Native’. This probably reflects the interest in more intensive land uses and potentially a lack of native vegetation areas to sample.

**Table 22** Assessment of representativeness of current soil quality sites with respect to land use, as determined from LCDB (2012): comparison of the expected % of samples for that land use based on area and the actual % of samples

| Land cover class | Area km$^2$ | Expected % | Actual % |
|---|---|---|---|
| Pasture | 132,924 | 55 | 50.3 |
| Cropping | 3,698 | 1.5 | 29.2 |
| Forestry | 20,406 | 8.4 | 6.9 |
| Native | 81,374 | 33.6 | 6.8 |
| Horticulture | 1,036 | 0.4 | 6.2 |
| Other | 2,399 | 1 | 0.7 |

### *Representativeness by soil order*

Representativeness of soil quality data by soil order follows a similar approach to the analysis by region and land use. Table 23 gives the expected and actual percentage of the soil quality samples. Oversampling is evident for all soil orders except Brown soils. For some soil orders (Pallic, Recent), the differences are less marked than for region and land use, perhaps reflecting the complex spread of soil order across regions and land use.

**Table 23** Assessment of representativeness of current soil quality sites with respect to soil order, as determined from LCDB (2012): comparison of the expected % of samples for that land use based on area and the actual % of samples

| Soil order | Area km$^2$ | Expected % | Actual % |
|---|---|---|---|
| Gley | 2,809,970 | 2.2 | 8.6 |
| Brown | 67,305,829 | 60.5 | 22.2 |
| Pallic | 14,975,139 | 18.5 | 26.5 |
| Podzol | 1,710,123 | 1.1 | 1.4 |
| Granular | 617,254 | 0.5 | 5.5 |
| Ultic | 1,285,693 | 1.2 | 5.8 |
| Recent | 11,104,975 | 9.1 | 11.8 |
| Melanic | 74,919 | 0.1 | 0.7 |
| Allophanic | 4,155,275 | 3.7 | 8.9 |
| Organic | 177,619 | 0.1 | 1.6 |
| Pumice | 2,795,672 | 2.9 | 6.3 |
| Raw | 300,162 | 0.2 | 0.8 |
| Anthropic | 132 | 0 | 0 |

Extension of this analysis would include a determination of representativeness based on land use and soil order at a national and regional level, as well as using the PFDI-generated land cover. One other aspect that hasn't been examined is the proximity of sampling sites to each other: greater representativeness is achieved if the sites are not in close proximity.

## 7.2 SWOT analysis

The SWOT (strength, weaknesses, opportunity and threats) analysis was based on that undertaken for the 500 Soils project by Hill et al. (2003) to provide an assessment of how different aspects have been addressed (Table 24). In essence, many of the same areas are relevant and the same comments apply. There has been increased awareness and uptake of soil quality monitoring by regional authorities. There is ongoing research to better understand soil processes and how this relates to land management and existing guideline or target value for different indicators and soil guideline values for trace elements are now available. However, there is still inconsistency in land-use classification and a need for better management of data and processes to facilitate regional comparisons and national reporting. There remains a clear role for central government participation to ensure the needs for truly national reporting are met.

**Table 24** SWOT analysis of current soil quality monitoring

| Criteria | Hill et al. 2003 | Current study |
|---|---|---|
| ***Strengths*** | | |
| The soils' properties and indicators are scientifically robust | All of the soil chemical and physical properties used are well established, internationally recognised and have been recommended for soil quality monitoring (e.g. see review by Doran et al. 1994). Use and interpretation of the properties for soil quality monitoring in New Zealand have been reported in peer-reviewed international journals (e.g. Francis & Knight 1993; Francis et al. 2001; Schipper & Sparling 2000; Singleton et al. 2000; Sparling, Schipper et al. 2000; Sparling, Shepherd et al. 2000b) | Not assessed in this study but same comment applies. There has been an increase in the extent of monitoring for trace element contaminants.<br>Some indicators/target values undergoing review (e.g. AMN, total N).<br>General underlying statistical basis of dataset reviewed by Stevenson et al., 2012) |
| Dynamic approach | The methodology used in the project has continually been refined as the project has progressed. Changes have been made in response to end-user requirements and improvement of methodology highlighted by assessment of annual results. | Not relevant in this study |
| National and local participation and awareness | The project has served to increase the national and local profile of soil quality. The level of national participation has increased. Five regions participated in the project in 1998/99 and 1999/2000, and 10 regional and district councils participated in 2000/01. | Ongoing soil quality monitoring and awareness have continued to grow, with 13 of the 16 regional and unitary authorities undertaking or about to commence SoE monitoring |

| Criteria | Hill et al. 2003 | Current study |
|---|---|---|
| Strong foundations for national monitoring programme | The 500 Soils project has provided a comprehensive national soil quality database (data set) | Although a database was created, it was not fully functional due to difficulty in tracking resampled sites over time (changes in naming systems complicated alignment of resampled sites). Further progression of a national soil quality database has been non-existent, and additional analyses (such as trace elements) have not been included.<br>As there will be greater scrutiny of data provenance (i.e. tracing results from laboratory to reporting) and data flow pathways under national reporting, this is an area of concern. |
| Filling information gaps – background soils concentrations | Not assessed | Trace element data used to determine background soil concentrations for trace elements for use in land management (e.g. cleanfill, managed fills) |
| ***Weaknesses*** | | |
| National and local focus | There has been some confusion regarding national and regional focus and objectives. Essentially the differences are related to scale of sampling and the detail of soil quality information required regionally and nationally. For national reporting the sampling requirements are less intensive than for those required for more detailed regional reporting. Spatial coverage and capture of state are important nationally, whereas many regions adopt targeted, issue-specific sampling | Same comments still apply |
| Sample depth | There has been some criticism that only the topsoil (0−10 cm) is sampled and not the entire soil profile. | One council uses a different sampling depth for the majority of samples used for soil quality reporting.<br>The desire to mitigate increased atmospheric $CO_2$ levels has increased the focus on soils as a carbon sink. However, the 10 cm depth is inadequate for monitoring soil C stocks. There also remains some concerns over land-use intensification effects on subsoils. |
| Spatial coverage (national) | There are currently some soil order / land-use combinations that have not been sampled (e.g. Semiarid Soils under horticulture), largely because some regional councils have not participated in the 500 Soils project. For a complete national representation of soil quality, all existing site combinations should be sampled and represented. | Same comments still apply, but note that most councils use genetic classification rather than NZSC for soil classification at an individual site level. |

| Criteria | Hill et al. 2003 | Current study |
|---|---|---|
| Commonality of land-use selection | There has been a lack of consistency between local government organisations (LGOs) in terms of land-use classification and selection. A common hierarchical land-use-type classification is being developed for future monitoring. Targeted monitoring will remain the approach of some LGOs in the future, but any national monitoring programme will be better able to incorporate these sites as required. | Despite a common hierarchical land-use-type classification being put forward in LMF 2009, inconsistencies in land-use categorisation still occur, and impede reporting at a national level. |
| Centralised data management | Data management has been partially an LGO and Landcare Research task. Centralised data management with national accessibility was not a priority of the 500 Soils project. Efficient sampling and information sharing will result from centralised data management, a consideration for any future monitoring. | Data management between councils remains inconsistent, and there is much discussion about how best to advance data management. This will be a focus for ongoing EMaR discussions. |
| Critical limits refinement | Two workshops, involving soil scientists, were held and initial critical limits developed for different soil land-use combinations. Application of these limits has been incorporated into the SINDI website (http://sindi.landcare.cri.nz/). | Target limits for soil quality parameters have been reviewed and refined since the 500 soils, and there are a variety of limits used by different councils.<br>Indicators have also been occasionally reviewed and there has also been a suggestion of more direct linkage to ecosystem services<br>Soil guideline values for the protection of ecological receptors (Eco-SGV) have been developed through the Envirolink process to assist in managing soil quality. |
| Inconsistent laboratory methods | Not assessed | Variations between methods for individual analytes by different laboratories (e.g. reporting of Olsen P on a volumetric vs a gravimetric basis) can impede comparison between regions and national reporting |
| ***Opportunities*** | | |
| Strong foundations for national monitoring programme | The 500 Soils project has not only provided a comprehensive national soil quality data set but has also paved the way for a scientifically based national soil quality monitoring programme. Internationally this is unique. | This study provides evidence of the extent to which a national monitoring programme has been developed. There is recognition of some of the areas where consistency needs to be achieved. |
| Future research/funding | A sound foundation has been set to secure future funding to continue soil quality monitoring in New Zealand. The success of the programme should make it less difficult to secure long-term funding at the local and national government level. | Same comments still apply for these areas – see also section 7.3 for discussion on other relevant programmes |

| Criteria | Hill et al. 2003 | Current study |
|---|---|---|
| Increasing soil quality knowledge | Excellent progress has been made in developing critical limits for soil quality indicators in response to LGO requests to refine the use of soil characteristics for determining soil quality status and estimates of recovery times for poor-quality soils. The further work required to fully develop this research would greatly benefit soil quality knowledge. | |
| Integration with other projects | The preliminary soil quality information is being used to refine targeted soil quality assessment and benefit soil-related research. There is potential to correlate the results with other soil research and extension projects (e.g. Visual Soil Assessment, Land Management Index and compaction trials on dairy and forestry). | |
| Centralised data management | Centralised data management would allow inter-regional use of soil quality data to reduce sampling costs, increase national sampling efficiencies, increase local soil quality knowledge, and promote interaction and collaboration between LGOs. | There is still a strong requirement for coordinated data management to ensure consistency in data collected and the ability to draw data together for national reporting. |
| ***Threats*** | | |
| Long-term commitment | The main threats to the success of an ongoing programme are the securing of funding, primarily at a regional level but also nationally; buy-in from regional and district councils; and continued financial assistance to maintain core national monitoring are essential. | Same comments apply, although the ongoing monitoring that has occurred indicates that buy-in has been achieved to a certain level. |
| | Long-term commitment to monitoring soil quality is required at local and national levels because of the long time scales over which soil quality can change (10s to 100s of years). | LMF has provided leadership in facilitating communication between councils, but there remains a clear role for central government participation to ensure the needs for truly national reporting are met. |
| | Regional councils and unitary authorities have the responsibility for environmental monitoring. They are also answerable to their regional ratepayers and will inevitably concentrate on environmental matters of local concern. Some regional councils have pursued independent lines that are not readily integrated into national reports. For this reason, and the assurance of a successful national overview and gap-filling, there is clearly a role for central government participation. | |

| Criteria | Hill et al. 2003 | Current study |
|---|---|---|
| Loss of key personnel | Personnel with knowledge of soil quality, and more so pedological experience, are becoming increasingly difficult to find in New Zealand. Those personnel currently involved stem from a previous science environment where these skills could be fostered. Nowadays, the science education and research environment does not provide the same opportunities, and there has emerged a shortfall of such personnel. | Same comments apply, with five respondents having worked in soil quality for <1 year, and loss of information due to personnel changes noted in the survey responses. |

## 7.3 Other programmes

In addition to the regional council soil quality monitoring programme and other soil quality investigations, there are a number of research programmes that have recently commenced and other programmes that could feed into the further development of national soil quality monitoring. A summary of these programmes is provided below.

*Research programmes*

Several major soil-related research projects have been funded within the past year. These include Soil Health: Oneone Ora Tangata Ora and S-map. These MBIE programmes began in October 2016 and will run for 5 years. The S-map programme focuses on S-map infrastructure, developing new pedo-transfer functions and refining existing functions, and expanding our knowledge of soil hydrological characteristics. The Soil Health programme focuses on soil resilience (the effects of land-use intensification on the entire soil profile), developing and integrating Māori concepts of soil health, and expanding the current soil health frameworks.

Councils and the LMF were briefed on both of these projects in February 2017 and their input is encouraged. Both programmes will feed data into the National Soil Data Repository (NSDR), and have also spurred the development of new tools to input and process soils data. We are also in the process of incorporating other data sets (such as the LUCAS data set) into NSDR, which can then be used as baseline data for comparing the effects of land-use intensification on soil properties.

Other related research includes several Sustainable Land Management and Climate Change (SLMACC) projects on quantifying soil C on a landscape level (led by Carolyn Hedley, Landcare Research) and the effects of irrigation on soil C (led by Paul Mudge, Landcare Research). These efforts will not only feed into regional- and national-level soil reporting, but will also complement other research programmes, such as the Our Land and Water National Science Challenge and the recently commenced Plant & Food Land use Suitability programme, which directly ties land-use effects to effects on the receiving environments (both terrestrial and aquatic).

### *Carbon and biodiversity monitoring soil sampling*

National biodiversity and ecosystem function (carbon) reporting currently utilises an 8 km grid-based plot network encompassing public conservation land and other forest and shrubland (Holdaway et al. 2016). This network was initially established by the Ministry for the Environment (MfE) for the purpose of carbon monitoring: the Land Use and Carbon Analysis System (LUCAS) natural and planted forest plot networks. The grid is currently being measured by the Department of Conservation (MacLeod et al. 2012) and MfE. Recently, regional councils have started planning ways to extend this plot network across the whole New Zealand landscape (Holdaway et al. 2016). This sampling has been undertaken on an 8 km grid, and is focused on vegetation. However, soil sampling is done as part of the sampling, although the frequency and extent are unclear.

This soil sampling is undertaken for the analysis of N, P and C, with the protocol described in DoC (2016). Briefly, subsamples are collected at nine points in the 20 × 20-m vegetation plot and aggregated into a single 500 g sample. The nine points are the intersections of the 5 m tapes inside the 20 × 20 m vegetation plot (Figure 4). At each of the nine points, a trowel is used to remove the litter layer, if present, and to collect the top 10 cm of mineral soil. Specifically, the trowel is used to dig a hole that is c. 10 cm deep with a diameter of c. 10 cm. The soil from each of these nine cores is placed in a large plastic bag, and mixed well on-site prior to removing c. 500g of the soil.

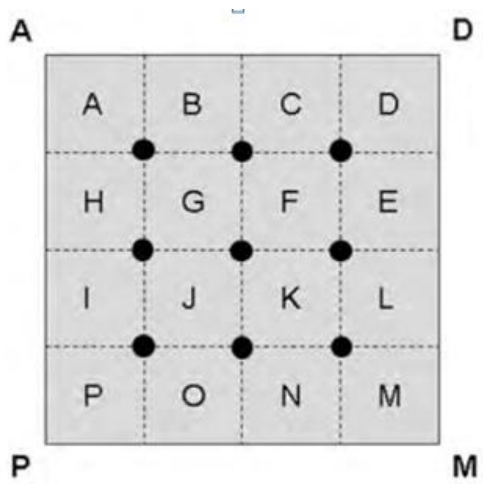


**Figure 4** Layout of 20 × 20 m plot showing the internal tape intersections where soils are sampled for the national biodiversity and ecosystem programme.

# 8 Conclusions

There was surprisingly limited information on soil quality programmes used internationally. An overview identified a number of different programmes, including geochemical studies used to establish geochemical baselines for the purpose of managing soil quality. These programmes may offer insight into solutions for gaps in the New Zealand programme.

A detailed stocktake of regional and unitary council soil quality, including trace elements, monitoring programmes and data management aspects, identified both similarities and differences in these programmes between councils. The detailed results of this stocktake are provided in three data files to allow further data interrogation, and are summarised in this report. Following are some of the key points arising from the stocktake.

- Twelve councils are currently undertaking ongoing soil quality monitoring and a 13th is currently developing a programme. The remaining three councils are unlikely to commence a soil quality programme in the near future due to budgetary constraints and council priorities
- Sites established under the 500 Soils programme are used by nine councils, although not all 500 Soils sites are included in ongoing monitoring by three councils. The 500 Soils sites are not included in soil quality programmes that have more recently commenced or are about to commence (four councils).
- Land use, often in combination with soil type, is used as the basis for site selection. However, there is variation in how councils classify land use.
- Councils use a combination of sources to determine soil classification (Table 6). While original 500 Soils sites were verified by a pedologist, soil order at some new sites has not been verified in the field.
- Site information collected largely follows that of LMF 2009, with councils noting that generally more detail is collected now than previously. All councils indicated that farm system and land-use information is collected, although this information is not clear or is inconsistent in data previously provided to Landcare Research.
- Most councils communicate with the landholder and obtain information on site management. Information on fertiliser management, irrigation, land-use history and crop management is often found useful by councils for either timing sample collection or interpreting results.
- Different naming conventions are used by councils for both site and sample identification, with the majority of councils using unique identifiers for samples, typically including the site identification. However, there are variations. No councils are using the original 500 Soils site identification.
- All but one council collect samples using a transect approach. This is generally as outlined by LMF (2009), although there is some variation. GPS is used to locate (and relocate, for subsequent sampling) current sites, and some councils also use photographs and physical site descriptors for reference. There are variations in the timing of sample collection, although the majority of councils collect samples in spring.

    - There is considerable variation in the specific soil quality chemistry analyses undertaken, although pH and total C were always analysed, and total N, AMN, Olsen P were most typically analysed, followed by $NO_3$, $NH_4$ (also analysed as part of AMN), and CEC (typically with exchangeable cations / base saturation). Most soil quality chemistry analyses were undertaken by Landcare Research, with a smaller number undertaken by Hill Laboratories – primarily in recent years. There are some differences in specific methods between laboratories that should be noted (e.g. volumentric vs gravimetric Olsen P methods). Analyses for HWC and HWN were undertaken by AgResearch.

- For the physical soil attributes, bulk density and macroporosity analyses are undertaken by all but one council, with the analyses typically carried out by Landcare Research. There still appears to be occasional confusion over macroporosity measurements (i.e. macroporosity measured at -5 kPa vs air-filled porosity measured at -10 kPa). There is also variation in whether councils, and on what samples, undertake aggregate stability, which is typically undertaken by Plant & Food Research.
- For trace element analyses the heavy metal suite (As, Cd, Cr, Cu, Pb, Ni, Zn) is most typically done, with Hg and F common additional elements (Table 11). One council analysed for Cd only, while another analysed for Cd and Zn only. Three councils undertake analysis of an extended suite of trace elements, with up to 38 elements analysed.
- Most councils aim to report differences between land use, change over time and comparison with guideline or target values. Most councils undertake basic statistical analysis (e.g. mean, median, range) on data for routine reporting. A smaller number of councils undertake more detailed data analysis.
- Reporting is most often directed to a mixture of the general public and the science community. All but one council indicated that technical reports are produced, although the frequency varies. Two councils reported producing fact sheets or report cards on the results, while seven councils report online, typically by uploading pdfs of reports.
- Seven councils report providing results to the landholder in the form of a copy of a relevant report, individual results or summary of results.

A preliminary assessment of representativeness based on land use and soil order identified practical constraints in determining representativeness as a key component of statistical analysis. Specifically, the LCDB is the primary source of spatial information on land cover and it can be used as a surrogate for land use. However, there is not necessarily a good match between council site classification and that identified through the LCDB. This is further confounded by inconsistencies in council classifications of land use.

There are further questions as to the point in differentiating between dairy and dry-stock systems, and whether it may be more appropriate, and less prone to misclassification, if these land uses were classified as pastoral systems, with a point of delineation based on measures of intensity/inputs (i.e. moving towards appropriately defined intensive and extensive pastoral systems). This may depend on public interest in effects associated with dairy.

There is under-sampling and over-sampling in some regions, based on the number of samples and the region's area. Based on land use, the actual sample coverage follows the expected coverage at a national level, although there is strong evidence of over-sampling in 'Cropping' and 'Hort', while under-sampling is evident in 'Native'. On the basis of soil order, oversampling is evident in Gley soils, while Brown soils are under-sampled. Among other soils the differences are less marked than for region and land use.

However, it should also be noted that from a statistical perspective achieving representativeness may not necessary; rather, a minimum number of sites may be all that is needed for sufficient statistical power to be able to determine differences. This preliminary analysis highlights the need for being clear on the purpose of determining statistical representativeness in order to undertake an appropriate assessment, as well as some practical constraints in undertaking this analysis.

It is not intended that this project provide recommendations or solutions arising from the stocktake. The aim is to provide information that can be used to inform EMaR and NEMS processes. Nonetheless, there are some key aspects that stand out for consideration for further development, many of which came through in the SWOT analysis. Specifically, greater consistency of land-use classification between councils is required, and it may be that a consistent approach to specifying both farm system and land use at the time of sampling yields maximum benefit with respect to assessing trends over time and comparison with target values – some of which may be land-use specific.

Consistency in the time of sampling minimises a source for variation in some soil properties, while consolidation and consensus on the appropriate target or guideline values to use would assist with consistent reporting.  Data management is an obvious weakness, with different systems (processes and databases) being used by different councils. Further, changes in site naming conventions and loss of institutional knowledge through changes in personnel at individual councils provide a challenging landscape for the accurate capture of historical data that can be confidently used to assess trends over time.

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## Appendix 1 – General survey questions

Questions provided on the survey spreadsheet circulated to all councils.

| **General information** | |
|---|---|
| Council: e.g. Tasman District Council | |
| Name and address of key council contact person: | |
| Name and address of person filling out survey: | |
| How long has the person answering the survey questions been involved with the soil quality monitoring programme at the council? | |
| ***Soil quality monitoring programme – General Questions*** | |
| 1. Has your council undertaken any soil quality monitoring for State of the Environment monitoring (SoE)? If yes, move to question 3, If no please move to question 2.. | |
| 2a) Have you undertaken any other soil quality monitoring e.g. Visual soil assessments? please specify | |
| 2b) Are you planning to undertake soil quality/trace element SoE monitoring in the near future? | |
| • if yes, please specify what monitoring you intend to undertake? (if you have selected sites already please also answer q 4&5). | |
| • if no, what are the main reasons you don't? | |
| (feel free to comment on anything WE HAVEN'T COVERED below. ) | |
| 3. Are there sites for which monitoring has been discontinued? If so, how many and why? E.g. change in regional plans, change in land use/ownership? | |
| ***General site questions*** | |
| 4. What landuse categories does your council use and what specific land uses activities/systems are included within those (e.g. horticulture – includes orchards and vineyards; cropping – includes maize, wheat, grains, market gardens etc )? | |

| **Landuse category** | **Used?** | **Land uses activities/systems included** |
|---|---|---|
| Horticulture | | |
| Cropping | | |
| Dairy | | |
| Drystock | | |
| Pastoral | | |
| Forestry | | |
| Background | | |
| Urban | | |
| Other (specify) (insert rows as required) | | |
| | | |

| | |
|---|---|
| 5. How have sites been selected? | |
| • Locations used in the 500 soils program? | |
| • Non-500 soils sites – landuse? soil type? soil order, combination, other? LMF guidance? | |
| • Please specify other site selection criteria. | |
| 6. When a general site location has been selected, are there any additional factors that you take into consideration when selecting the specific site for monitoring e.g. farmer has directed you to a particular paddock, avoid water troughs, camp areas? Please describe. | |
| 7. How has the site location at each time of sampling been recorded? E.g. map grid references, site description, GPS (specify any changes over time e.g. from 2005 GPS recorded). | |
| 8. Where GPS is used, what point/s are recorded e.g. start, middle, end of transect? Please specify. | |
| 9. How are sites relocated at time of next sampling? (e.g. return to GPS point, return to same paddock?) please specify. | |

| ***Sample collection*** | |
| --- | --- |
| 10.What time of year is sampling typically undertaken? | |
| 11. How frequently are sites re-sampled, and what is the basis for frequency of resampling sites? | |
| 12. Describe any factors that may influence resampling time e.g. budget. | |
| 13. How are samples for soil chemistry (e.g. pH, Total C, trace elements) collected? | |
| a) Following LMF protocol (i.e. 25 cores along 50 m transect to 10 cm)? (please note any variation from this protocol below). | |
| b) Other – please describe (any slight variation from LMF should be noted). | |
| 14. On land where there are furrows – do you collect samples across or along the furrows? If across, do you sample in the row and between the rows, or just in the planted row, or in wheel tracks? | |
| 15. If you collect samples for macroporosity and bulk density how are they collected? | |
| • As per LMF guidance – 75 x 100 mm ring at 15, 30 and 45 m along transect? | |
| • Other – please specify | |
| 16. Are you aware there are different matric potentials for macroporosity? | |
| • What do you use/report? | |
| 17. If you collect samples for aggregate stability, how are they collected? | |
| • As per LMF guidance – 10 cm square (10 cm high(deep) x 10 cm wide) and 1–3 cm thick from a fresh vertical soil face | |
| • Other – please specify | |
| 18. Has sample collection changed over time? If so, please describe changes. | |
| ***Site information*** | |
| 19. What information is recorded at time of site establishment? | |

| | |
|---|---|
| • Full site description as per LMF guide? | PLEASE PROVIDE ANSWERS ON THE ANALYTE, LAB METADATA SHEET |
| • For 500 soil sites, do you have a record of the 500 soils site information sheets? | |
| • Site management history (template provided in LMF guide) | |
| • Soil profile | |
| • Additional information | |
| 20. How has sample id been recorded – is there a specific protocol? | |
| 21. Have site names changed over time? In particular, have site names changed from the original 500 soils project names? Why? | |
| 22. What soil classification information is recorded? E.g. soil order, soil series | |
| • If other – please specify | |
| 23. How has soil class/type been determined? E.g. using soil maps, field-based soil profile description, not sure. Specify | |
| • Was a Landcare Research pedologist, or person with pedological training and experience involved? | |
| 24. Have any soil chemistry or other measurements been undertaken on a one-off basis? E.g. Anion storage capacity (P retention) etc? to assist classification? | |
| • If yes – please specify | |
| 25. Has soil classification been confirmed? E.g. through field assessment and soil chemistry? | |
| 26.What site information is recorded at each time of sampling? | |
| • Do you record farm system (e.g Dairy farm) and landuse of paddock (e.g. pasture, fodder crop) at each time of sampling? | |
| • Do you record the condition of the site at time of sampling, e.g. just harvested forestry? | |

| | |
|---|---|
| • Other information | PLEASE PROVIDE ANSWERS ON THE ANALYTE, LAB METADATA SHEET |
| 27. Has site information recorded changed over time? | |
| • If so, how? | |
| 28. Do you ask the landowner about land management (e.g. application of fertiliser may be relevant for interpretation of results) | |
| • If yes, how? What is your response rate? | |
| 29. Of site information recorded when undertaking the soil sampling, what do you find useful e.g. for collecting, reporting and interpreting the results? | |
| 30. Of site information recorded about the farmer's management, what do you find useful e.g. for collecting, reporting and interpreting the results? | |
| **Sample analysis** | |
| 31. What analyses have been conducted and where? – please identify the timeframe over which analyses have been undertaken and by which laboratory (e.g. soil quality: Landcare Research 2000-2006, Hill laboratories 2007-2012, Eurofins, ARL , Plant and Food, other)? | |
| ***Soil quality*** | |
| • Soil chemistry – pH, Total C, Total N, mineralisable N/anaerobically mineralisable N (AMN), Olsen P | PLEASE PROVIDE ANSWERS ON THE ANALYTE, LAB METADATA SHEET |
| • Soil physical analyses: macroporosity, bulk density | |
| • Aggregate stability | |
| • Extended soil chemistry – e.g. CEC, EC, base-saturation, P-retention (ASC), (specify when and on what sample additional analyses have been undertaken) | |
| • Microbial community DNA analysis (specify when and on what sample additional analyses have been undertaken) | |

| | |
|---|---|
| • Anything else e.g. particle size analysis/clay fraction, water retention curve, hydraulic conductivity? Visual soil assessment? Hot-water carbon. Include analyses that have been done on a one-off basis | |
| ***For contaminant analyses (metals, organics) – has screening level or trace level analyses been undertaken (screening level analyses have a higher detection limit)?*** | PLEASE PROVIDE ANSWERS ON THE ANALYTE, LAB METADATA SHEET |
| • Heavy metal suite – As, Cd, Cu, Cr, Pb, Ni, Zn | |
| • Additional analytes – U, Hg, F (specify) | |
| • Extended TE suite (list # elements) (variation in # indicates whether any variation in # or range over years… | |
| • Organic contaminants (e.g. organochlorine pesticides, PAHs) | |
| 32. Have you undertaken any comparative analyses? eg method comparisons, row- inter-row comparison? | |
| • If so please describe | |
| 33. Do you archive the samples collected for potential future analysis? | |
| • If so, how? E.g. From which laboratory or laboratories do you get samples back from. Are they sieved/ground and air-dried? etc. | |
| ***Sampling Inventory*** | |
| 31. Please compile an inventory of all sites your council has monitored over time for SoE reporting using the **Sampling Inventory sheet and Analyte, lab, metadata sheets** (note: these have been pre-populated with known data, please cross-check and add any missing data), including for each site: | |
| • Site id, year established | PLEASE PROVIDE ANSWERS ON THE SAMPLING INVENTORY SHEET |
| • Years sampling has been undertaken at each site (and month sampled, if known) | PLEASE PROVIDE ANSWERS ON THE SAMPLING INVENTORY SHEET |
| • Analyses undertaken by which laboratories (record on analyte and lab summary sheet) | PLEASE PROVIDE ANSWERS ON THE ANALYTE, LAB METADATA SHEET |
| • Site information recorded at time of sampling? | PLEASE PROVIDE ANSWERS ON THE ANALYTE, LAB METADATA SHEET |

| | |
|---|---|
| • Land-use at time of establishment and at last sampling | PLEASE PROVIDE ANSWERS ON THE SAMPLING INVENTORY SHEET |
| ***Data analysis and management*** | |
| 32. What analyses do you undertake on your data – e.g. landuse differences, change over time, comparison with guideline? Please specify | |
| 33. What calculations are undertaken prior to reporting e.g. area weighting? Etc | |
| 34. How do you report macroporosity data– is it the average of 3 reps? Or other? (Please specify) | |
| 35. Is bulk density used in the calculation of some reported measurements? | |
| • If so, what measurements? | |
| 36. What statistical analysis do you use to analyse your data for routine annual reporting? | |
| 37. What statistical analysis do you use for more in-depth reporting, if any? E.g for an analysis every five years or so. | |
| 38. How do you deal with outliers and results that are less than the Limit of detection (LOD) in your reporting? E.g. set as 1/2LOD, set as zero? | |
| 39. Please provide a description of your council's processes and data management systems used for soil quality/trace element SoE soil data, including: | |
| • In what form is data stored e.g. excel spreadsheets – data structure (if possible, please provide an example of typical structure), access database – specifically Hilltop WISKI (please specify what fields you use). | |
| • Do lab results feed directly into your database? | |
| • If so, have you set up additional fields for soil quality in your database? If so, please specify | |

| | |
|---|---|
| • Briefly describe any data checking process used when collating the data (Specify N/A if no process used) | |
| 40. Do you engage external consultants /CRIs to assist with the analysis and reporting? | |
| • If yes, on which aspects do they assist (e.g. analysis only or analysis and report preparation). | |

41. What source of information do you use for the reporting of target or guideline values for soil quality indicators (pH, total C etc. SINDI,) – Complete Table below

| **Source** | **pH** | **Total C** | **Total N** | **Mineralisable N** | **Olsen P** | **Bulk density** | **Macro-porosity** | **Aggregat e stability** |
|---|---|---|---|---|---|---|---|---|
| LMF 2009 | | | | | | | | |
| SINDI database | | | | | | | | |
| Sparling et al 2003, 2008 | | | | | | | | |
| Mackay et al 2013 | | | | | | | | |
| Other (specify) | | | | | | | | |

42. What source of information do you use for the reporting of target or guideline values for trace elements (e.g. biosolids guidelines)

| **Source** | **As** | **Cd** | **Cr** | **Cu** | **Pb** | **Ni** | **Zn** | **Other (specify)** |
|---|---|---|---|---|---|---|---|---|
| NZWWA (2003) Biosolids Guidelines | | | | | | | | |
| Tiered Fertiliser Management System (Cd only) | | | | | | | | |
| Ecological Soil Guideline Values (Envirolink Tools project) | | | | | | | | |
| Canadian Guidelines (CCME) | | | | | | | | |
| Alloway 2008 | | | | | | | | |
| Other (specify) | | | | | | | | |

| ***Reporting*** | | |
|---|---|---|
| 43. Do you report on your soil quality/trace element SoE monitoring at a regional level? | | |
| • If so, how? | **Yes or No** | **Frequency?** |
| • Technical reports? | | |
| • Fact sheets? | | |
| • Web | | |
| • Scientific papers? | | |
| • Other -please specify | | |
| 44. What type of audience is the reporting directed toward (e.g. general public, science audience only, a mixture)? | | |
| 45. How do you communicate results with landholder? | | |
| 46. Do you provide advice to landholder based on results? | | |
| ***Other investigations*** | | |
| 47. Has your council undertaken any other investigations for soil quality (excluding investigations for contaminated sites for NESCS)? If so, please describe the sampling undertaken, including purpose of investigation, number of sites sampled, analyses undertaken, details of any reports. Insert a new row for each study. | | |
| • Other investigations | | |
| • Other investigations | | |
| • Other investigations | | |
| **Publications** | | |

| | |
|---|---|
| 48. Please provide a list of relevant reports and other publications produced by/for your council. Please include annual reports for SoE reporting, the comprehensive reports that councils do every 5 years or so, and any relevant journal papers or conference papers published on the monitoring results or methodology. Please provide for each report/publication: Authors, Year, Title, Report number, Journal with volume, issue, & page numbers (where applicable), and a web link (where available). Note – this list of reports and associated publications will be very helpful if we need further detail on your programmes. A comprehensive list of relevant reports and other publications should provide an excellent resource for the LMF and yourselves into the future.<br><br>Where provided references listed are those provided in response to the EMaR survey undertaken in 2014 – please add any missing references, including any publications produced since 2014. Please provide a list of any soil quality reports and associated publications that have been produced since EMAR 2014 | PLEASE PROVIDE ANSWERS ON THE PUBLICATIONS SHEET |

## Appendix 2 – Soil quality, trace elements, and nutrient use publications

This bibliography has been compiled from a survey previously conducted through EmaR and additional publications provided as part of this project.

*Annual & Technical Reports*

Auckland Council

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Stevenson, B., 2010. Soil quality of dairy sites in the Auckland region 2010. Prepared by Landcare Research for Auckland Regional Council. Auckland Regional Council Technical Report 2010/026.

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**Bay of Plenty Regional Council**

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Rijkse, W.C., Guinto, D., 2010. Soils of the Bay of Plenty Volume 1: Western Bay of Plenty. Bay of Plenty Regional Council Environmental Publication 2010/11-1. http://www.boprc.govt.nz/media/32401/EnvReport-201011-SoilsBayofPlentyV1WesternBay.pdf

Rijkse, W.C., Guinto, D., 2010. Soils of the Bay of Plenty Volume 2: Central Bay of Plenty. Bay of Plenty Regional Council Environmental Publication 2010/11-2. http://www.boprc.govt.nz/media/32404/EnvReport-201011-SoilsBayofPlentyV2CentralBay.pdf

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**Environment Southland**

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