National Environmental Monitoring Standard

Soil Quality and Trace Elements

Sampling, Measuring, and Managing Soil Quality and Trace Element Data

Version 1.0.0

Date of Issue: July 2022

Disclaimer

The Ministry for the Environment does not necessarily endorse or support the content of the publication in any way.

Copyright

The National Environmental Monitoring Standards

The current suite of National Environmental Monitoring Standards (NEMS) documents, Best Practice Guidelines, Glossary and Quality Code Schema can be found at www.NEMS.org.nz.

Implementation

When implementing the Standards, current legislation relating to health and safety in New Zealand and subsequent amendments and the NEMS Best Practice Guidelines shall be complied with.

Limitations

It is assumed that as a minimum, the reader of these documents has undertaken industry-based training and has a basic understanding of environmental monitoring techniques. Instructions for manufacturer-specific instrumentation and methodologies are not included in this document.

The information contained in these NEMS documents relies upon material and data from a number of third-party sources.

The documents do not relieve the user (or a person on whose behalf it is used) of any obligation or duty that might arise under any legislation, and any regulations and rules under those Acts, covering the activities to which this document has been or is to be applied.

The information in this document is provided voluntarily and for information purposes only. Neither NEMS nor any organisation involved in the compilation of this document guarantee that the information is complete, current or correct and accepts no responsibility for unsuitable or inaccurate material that may be encountered.

Neither the NEMS Steering Group, nor any employee or agent of the Crown, nor any author of or contributor to this document shall be responsible or liable for any loss, damage, personal injury or death howsoever caused.

Development

The National Environmental Monitoring Standards (NEMS) Steering Group has prepared a series of environmental monitoring standards on authority from the Regional Chief Executive Officers (RCEOs) and the Ministry for the Environment (MfE).

The strategy that led to the development of these Standards was established by Jeff Watson (Chairman 2013) and Rob Christie (Project Manager 2013). The current Steering Group comprises Michael Ede (Chairman), Phillip Downes, Martin Doyle, Glenn Ellery, Jon Marks, Charles Pearson, Jochen Schmidt, Fiona Hodge, Abi Loughnan, with project management by Raelene Mercer.

The development of this Standard involved consultation with regional and unitary councils across New Zealand, industry representatives and Manaaki Whenua – Landcare Research. These agencies are responsible for the majority of continuous environmental-related measurements within New Zealand. It is recommended that these Standards are adopted throughout New Zealand and all data collected be processed and quality coded appropriately to facilitate data sharing. The degree of rigour with which the Standards and associated best practice may be applied will depend on the quality of data sought.

This document has been prepared by a core working group comprising Reece Hill (lead technical writer – Landsystems), Bryan Stevenson (Manaaki Whenua Landcare Research), Haydon Jones and Matt Taylor (Waikato Regional Council), Matt Oliver (Marlborough District Council), Ognjen Mojsilovic (Environment Canterbury) and Staci Boyte (Horizons Regional Council). The input of NEMS Steering Group members into the development of this document is gratefully acknowledged.

The core working group was supported by representatives from the regional sector's Land Monitoring Forum (LMF). Members of the LMF contributed material, attended meetings and/or provided review comments.

Funding

The primary funders of the National Environmental Monitoring Standards project are Ministry for the Environment, and New Zealand regional councils and unitary authorities. Other financial and in-kind support to the overall NEMS project has been provided by the following organisations:

- National Institute of Water and Atmospheric Research Ltd (NIWA)
- Ministry of Business, Innovation and Employment – Science and Innovation Group
- GNS Science
- Genesis Energy
- StatisticsNZ
- Contact Energy
- Meridian Energy
- Mercury New Zealand Limited

Review

This document will be assessed for review by the NEMS Steering Group within one year of its release and thereafter will be assessed for review approximately once every two years. Further details on the review process can be found at www.nems.org.nz.

TABLE OF CONTENTS

Terms, Definitions and Symbols

Relevant definitions and descriptions of symbols used in this Standard are contained within the NEMS *Glossary* available at www.nems.org.nz.

Note: The definitions below will be removed from this document and transferred to the NEMS Glossary at the first revision of this document.

For the specific purposes of this document, the following definitions apply:

Term	Definition
Soil quality	Soil quality is the capacity of a soil to function, sustaining plant and animal productivity, maintaining or enhancing water and air quality, and supporting human health and habitation. Soil quality and soil health are often used interchangeably, though some maintain there is a difference between the two.
Soil quality indicators	Measurable soil attributes used to describe the condition of a soil and its capacity to perform its functions.
Trace element	A chemical element that is normally found in minute amounts in the soil. While some trace elements may be essential to plant and animal growth (e.g. zinc, copper, chromium), when in excess, trace elements are often considered contaminants.
pH	A measure of the acidity or alkalinity of a soil.
Total carbon	A measure of the total amount of all forms (organic and inorganic) of carbon in the soil.
Total nitrogen	A measure of the total amount of all forms of nitrogen in the soil.
Olsen phosphorus	A measure of the amount of phosphorus available for plant and microbial uptake.
Bulk density (fine dry bulk density)	The weight of soil in a given volume. This is a measure of how densely soil particles are packed in situ in the field.
Volume weight	A measure of how densely a soil is packed after it is prepared for laboratory analysis (i.e. the weight of air dried and ground >2 mm soil per a given volume).
Anaerobically mineralisable nitrogen	A laboratory measure of the amount of nitrogen that can readily be supplied to plants through the decomposition of soil organic matter.

Air-filled porosity (at -10 kPa)	The proportion of soil volume drained between the pressure levels of 0 and -10 kPa on the soil-water desorption curve (i.e. pores >30 um equivalent cylindrical diameter). The terms air-filled porosity (at -10 kPa) and macroporosity (at -10 kPa) are often used interchangeably.
Aggregate stability	A measure of the ability of soil aggregates to resist disruption when outside forces are applied.

Normative References

This Standard should be read in conjunction with the following references:

- NEMS *Glossary*
- NEMS *Quality Code Schema*

About this Standard

Introduction

Soil quality and trace element monitoring involves the regular measurement of soil properties (the indicators) at sites selected across a region to represent various combinations of land use and soil. The results of this monitoring are used for State of the Environment reporting and informing policy development and soil management decisions. This document outlines the monitoring procedures and the standards for soil quality and trace element monitoring in New Zealand.

Objective

The objective of this Standard is to ensure that regional soil quality and trace element monitoring data are consistently gathered, processed and archived over time and across New Zealand and are suitable for regional and national State of the Environment reporting. This document is made up of two sections: the first section is the Standard and the second section contains supporting information that practitioners are required to implement in order to achieve the Standard.

Scope

This Standard covers the following aspects of soil quality and trace element monitoring:

- suite of soil quality indicators
- suite of trace elements
- timing of sampling
- site location
- site description
- in-field sampling
- sample management
- laboratory quality assurance
- laboratory analysis
- data management.

The Standard includes both soil quality indicators and trace element data as they use the same soil samples collected at a site. The Standard applies to the sampling of an individual site at one point in time and does not include requirements for soil quality indicator and trace element monitoring programme design. However, guidance for programme design is included in the supporting information, as good programme design is considered important for robust aggregation of regional data for national reporting.

Specific equipment is not a requirement for the Standard, but guidance on useful equipment for site and sampling procedures is provided in Annex 2.

Exclusions

This Standard does not include:

- setting target ranges for soil quality indicators and trace elements
- interpretation and reporting of results
- development of new templates associated with the Standard.

The Standard – Soil Quality and Trace Elements

Primary Method

For data to meet the Standard (and to secure a QC 600 rating) the Primary Method shall be adopted, and the following shall be achieved:

Soil quality indicators *Section 4*	The indicators provide a scientifically robust indication of the soil quality state at the site.
Trace elements *Section 5*	The data provide a scientifically robust indication of the soil trace element state at the site.
Timing of sampling *Section 7*	Sampling is undertaken in spring or autumn and for repeat sampling of sites, samples are taken in the same season (spring or autumn) at each sampling.
Site location *Section 9.1*	The site has site and transect location metadata that allow accurate relocation.
Site description *Section 9.1*	The site has detailed metadata including a site description and land management information.
Soil characterisation and classification *Section 10*	A site soil profile description includes all soil characteristics sufficient to classify the soil order.
Sample field collection *Section 7*	Samples are collected in a way that ensures they are representative of the site and are of high quality, minimising bias and disturbance.
Sample management *Section 13.12*	Soil samples are packaged, labelled, stored and transported to the laboratory to minimise physical deterioration, contamination, loss or mistaken mixing of site samples.
Laboratory certification *Section 12*	Laboratories meet quality assurance and quality control requirements.
Laboratory analysis *Section 13*	Laboratory analysis follows required methods and data are provided in required units (or with the ability to convert). Data are presented in electronic format.
Data management *Section 14*	All data are recorded and managed in organisational databases with backup and the ability to extract correct data in a form required for regional and national reporting. Data are regularly backed up.

Requirements

The following criteria apply to the Primary Method procedures:

Indicators and data	Soil quality indicators *Section 4*	Includes all the following: pH, Olsen phosphorus, total carbon, total nitrogen, anaerobic mineralisable nitrogen, air-filled porosity (at -10 kPa), bulk density and aggregate stability.
	Trace elements *Section 5*	Includes all the following: Total recoverable As, Cd, Cr, Cu, F, Pb, Ni, and Zn.
Timing of sampling *Section 7*	Timing of sampling	Sampling is undertaken in spring or autumn to ensure the correct soil moisture, avoiding seasonal and weather impacts (eg, cultivation, excessively dry or wet soils, harvesting); repeat sampling of existing sites is in the same season.
Site metadata *Section 9*	Site location	Includes site property address; property contact details; site location details (eg, photos); GPS location of transect and sampling cores.
	Site description	Includes all required site description information specified as the minimum standard.
	Land management	Includes all required land management information specified as the minimum standard.
Soil characterisation and classification *Section 10*	Soil profile description	A soil profile description with a minimum set of soil characteristics recorded based on Milne et al. (1995); undertaken by a Suitably Qualified Person; includes a soil profile photo.
	Soil classification	Soil profile description characteristics are sufficient to classify the soil order according to the *New Zealand Soil Classification*; undertaken by a Suitably Qualified Person.

Sample field collection *Section 7*	Soil transect (bulked cores of 10 cm depth for most analyses)	50 m long, follows contour or land management, avoids disturbance; uses method in Standard. Core sample (2.5 cm diameter) 0–10 cm depth every 2 m (25 subsamples) bulked; uses method in Standard.
	Soil cores (7.5 cm depth for air-filled porosity and field undisturbed bulk density)	Three cores per site; 10 cm diameter to 7.5 cm depth at three even spacings along transect; uses method in Standard.
	Spade sample (aggregate stability only)	Three replicates per site; spade with square (15 cm x 15 cm) of 10 cm depth; uses method in Standard.
	Stone and fines content and volume (stony soils)	Three replicates per site; 20 cm x 20 cm pit to a depth of 10 cm; uses method in Standard.
Sample field management *Section 13.12*	In-field sample management	All samples are securely bagged and clearly and permanently labelled.
	Sample storage and transit	All samples are securely stored for transit and transported to minimise sample deterioration and contamination. Laboratory forms are completed as required. Sample storage (eg, temperature) and transit time from the field to the laboratory meet laboratory requirements.
Laboratory certification *Section 12*	Certification	Where certification is available the laboratory provides evidence of current certification.
Laboratory analysis *Section 13*	Analytical methods	As specified in this Standard, with minor variations permitted; all analytical methods are documented and provided by the laboratory. Detection limits are provided for each analytical method.
	Laboratory results	Data are provided on a weight basis or with ability to covert from volume to weight basis using the laboratory-provided volume weight.

		Provided in electronic format.
Data management *Section 14*	Data preservation and storage	Data are entered into an organisational database and are backed up.

Alternative Method

The Standard also permits the following Alternative Method for pastoral and cropping sites. Data collected using the Alternative Method can only secure a maximum QC 500 rating because of the different soil depths specified in the method. The Alternative Method shares all the same measurement objectives and requirements as the Primary Method except for:

- Sample soil depth
- In-field soil core sampling

Requirements

The following alternative criteria apply to the Alternative Method procedures:

Sample field collection *Section 3.2*	Bulked soil core sampling (for most analyses)	Three replicates per site; three soil cores (7 cm diameter) per replicate; 0–15 cm depth, bulked per replicate.
	Soil core (for air-filled porosity and bulk density)	Three replicates per site; One intact soil core (10 cm diameter) to 7.5 cm depth per replicate.

1 Introduction

In New Zealand, monitoring the state of the environment is a specific requirement of regional authorities (regional councils and unitary authorities) under the Resource Management Act 1991 (RMA). The purpose of the RMA (section 5) is to promote the sustainable management of natural and physical resources, including safeguarding the life-supporting capacity of the soil, to ensure it will meet the foreseeable needs of future generations. Section 35(2)(a) requires local authorities to monitor the state of the whole or any part of the environment to the extent that is appropriate to enable the local authority to effectively carry out its functions under the RMA. Monitoring soil quality and soil trace elements is considered part of this requirement.

To increase soil quality understanding in New Zealand a Sustainable Management Fund Project (#5089), *Implementing Soil Quality Indicators for Land* (referred to in this Standard as the '500 Soils Project'), was initiated in 1999 and completed in 2001 (Sparling et al., 2000, 2001a, 2001b). The project tested potential soil quality indicators across a range of soils and land uses, defined a key set of soil quality indicators for measuring and assessing soil quality, and established approximately 500 initial monitoring sites (roughly one site per 25 km^2) across participating regions (10 of the 16 regions). Prior to the 500 Soils Project there was no nationally consistent, scientifically based soil quality monitoring data for New Zealand (Hill et al., 2003; Sparling and Schipper, 2004).

Following the completion of the 500 Soils Project, a review of the project was undertaken by the Land Monitoring Forum[1] (Hill et al., 2003) to provide recommendations for establishing regional soil quality monitoring. Subsequently, 13 of the 16 regional authorities have implemented regular regional soil quality monitoring and reporting programmes following methodologies based on the 500 Soils Project.

Soil quality and trace element monitoring has been on a voluntary basis, providing regions with flexibility in their monitoring approach and allowing them to report on issues most relevant to their region (Cavanagh et al., 2017). However, this has resulted in inconsistencies in monitoring across regions (Parliamentary Commissioner for the Environment, 2019), and therefore accurate, regular national-level reporting, required under the Environmental Reporting Act 2015, is not possible. Thus, a more uniform approach to regional-level monitoring and reporting of soil quality and trace elements is required.

A review of regional soil quality and trace element State of the Environment (SoE) monitoring programmes identified steps for improving the national consistency of SoE reporting including soil quality and trace element monitoring and data management (Jones et al., 2015). An identified step was improving future monitoring and data management through the National Environmental Monitoring Standards.

Overall, the review concluded that the New Zealand approach to soil quality and trace element monitoring 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 not overly comprehensive, it is cost-effective and enables regional authorities to establish ongoing monitoring. A contrasting international example is the European (ENVASSO)

[1] A regional sector special interest group formed by Local Government New Zealand in 1999. The forum represents professional and technical experts from all New Zealand regional councils and unitary authorities in roles relating to land and soil science, research, monitoring and input into policy development.

programme, which was very thorough, covering much of Europe, but never repeated because of the cost (Cavanagh et al., 2017).

Inherent to regional soil quality and trace element monitoring for SoE purposes is the interdependence of the soil chemical, biological and physical quality indicators. For this reason, this Standard recommends adopting a programme that includes all soil quality indicators as opposed to sampling a sole, or a limited set of, indicators.

At present, there are 13 (out of 16) regional authorities in New Zealand that undertake soil quality and trace element monitoring, mostly in line with the existing national soil quality monitoring guidelines developed and published by the Land Monitoring Forum (Hill and Sparling, 2009). Some regions have been monitoring soil quality for more than a decade.

Since the publication of the national guidelines, several pieces of work have been undertaken that have highlighted method and data storage inconsistencies, explored indicator changes, and revised indicator 'target' ranges. Therefore, the development of a soil quality (including trace elements) NEMS (this Standard) is timely in order to update and formalise the existing national guidelines.

2 Regional monitoring programme guidance

In this section

This section provides guidance on how to select sites for the regional programme and the frequency of sampling. **These are recommendations, not requirements of this Standard.**

2.1 Programme objectives

Individual site soil quality indicator and trace element data are collectively part of regional SoE monitoring and reporting programmes. Although this Standard does not include requirements for overall programme design, the following regional programme objectives could be considered:

- To provide a representative assessment of the quality of the region's soil resource state and trends over time.
- To assess soil quality across a range of land uses and soils representative of the region's soil resource.
- To provide an early warning system to identify the effects of primary land uses on long-term soil quality (physical, chemical, biological) and soil trace elements.
- To assist in the detection of spatial and temporal changes in soil quality and soil trace elements.
- To integrate with other regional monitoring (eg, groundwater monitoring).
- To collect scientifically robust data.
- To provide data that can be aggregated for national reporting.

2.2 Programme site selection

Sites should be selected to represent the major soils and land uses of the region. This is done to reduce bias.

Sites are classified according to land use type (refer to section 6.1) and soil order (Hewitt, 2010).

A Geographic Information System (GIS) can be useful for combining land use map information with soil map information to derive a potential set of sites and narrow down the parts of the region from which potential sites (and their landowners) can be selected.

Site selection can be done initially using regional vegetation cover maps, satellite or aerial photographs and soil maps to identify land use type and soil combinations within the area. In practice, the primary objective at a regional scale is to select sites across all major land use types and weight the number of sites based on the area of different soils.

The weighting of sites by soils can be done using any available soil map information (eg, soil series, S-map). However, the site should be classified to at least the *New Zealand Soil*

Classification 'soil order' (Hewitt, 2010) for reporting purposes. S-map Online[2] provides a full soil classification for every soil sibling, as well as a search function for correlating S-map soil siblings with soil series.

A further complication is that the soil on a map may be different to the soil in the field – mostly due to map scale constraints. For this reason, a field soil profile description is required for each site. This needs to be completed or overseen by a Suitably Qualified Person (a pedologist).

Once potential sites have been identified they should be confirmed by contacting the landowners and by site visits. Experience has shown that on-site visits and soil characterisation checking are essential to confirm the site is as mapped. It is useful to have a list of contingency sites in case those originally selected have subsequently changed in land use or do not conform to the mapped soil order.

Criteria to be considered when selecting and confirming sites include:

- Is the site representative of its type and does it agree with the mapped land use and soil order?
- Is the landowner willing to provide access?
- Are the any problems with access and in removing soil samples?
- Will the site be accessible for future sampling?
- Can information on current use and management be obtained?
- Is the land use history known?
- Are there any planned future changes in land use?

In most instances the number of sites in a region's soil quality monitoring programme will be limited by resource constraints or availability of sites (due to the size of the region). In these situations, consideration should be given to targeted sampling of land uses of concern and whether the sampling will be spatially representative of the areas under the different land uses.

2.3 Site stratification and weighting

Hill et al. (2003) and Stevenson et al. (2012) indicated that a minimum of 30 sites per land use type is required to provide statistically robust data for monitoring and reporting. In theory, this provides some guidance for site number requirements at a regional level (ie, a similar number of samples would be needed at a regional level if the same range of land use type and soil indicator variability were expected).

In reality, it may be difficult for some regions to locate 30 sites for each land use type.

The guidance recommended in this Standard is to establish a consistent minimum number of sites across all land use types and add additional sites according to the area of land use type and soil order combinations in the region.

[2] https://smap.landcareresearch.co.nz/

2.4 Frequency of sampling

Soils may take many years to reach an equilibrium or 'steady state'. For example, Parshotam and Hewitt (1995) estimated it would take at least 50 years for the organic matter in a degraded semi-arid land in Otago to rebuild to its nondegraded level. Haynes and Tregurtha (1999) estimated that organic matter decline under intensive vegetable production in Pukekohe took 80 years to reach a new, much lower, equilibrium. Sparling et al. (2000) noted that other soil properties (total N, bulk density) took up to 50 years to establish equilibrium. In contrast, soil fertility can show very rapid changes following fertiliser and lime applications.

To identify soil quality indicator and trace element data trends, sites will need to be resampled over time. A sampling frequency of at least once every five years is recommended for all land use types with the exception of exotic forest and indigenous vegetation, which can be resampled every ten years. This frequency of resampling should provide sufficient data for long-term trend analysis.

In some circumstances (such as land use change at a site or intensive land use) sampling frequency can be increased. Table 1 provides additional guidance for the frequency of resampling land use types and land use change.

Table 1: Recommended sampling frequencies for general land uses and land use change

Land use type	Purpose of monitoring	Frequency	Examples
Arable cropping Intensive pastures	Monitor cumulative effects of land use over several years. Show effect of changed land use on soil characteristics.	1–5 years	Compare continuous cropping with mixed cropping. Monitor organic matter status. Monitor soil recovery after compaction or depletion.
Extensive pasture (drystock)	Monitor slowly changing soil properties.	2–5 years	Monitor nutrient status to look for depletion.
Intensive pasture (dairy, dairy support, intensive beef)	Monitor accumulative effects of land use over several years. Show effect of changed land use on soil characteristics.	1–5 years	Monitor organic matter, nutrient status, and physical condition. Monitor soil recovery after conversion.
Pasture to woody vegetation conversion (eg, retirement to indigenous)	Monitor soil changes following conversion from pasture and during indigenous vegetation establishment.	1–3 years for the first 10 years, then treat as indigenous vegetation site.	Monitor organic matter, nutrient status, and physical condition. Monitor soil recovery after conversion.

Pine to pasture conversion	Monitor soil changes following conversion from forestry and during pasture development.	1–3 years for the first 10 years, then treat as pasture site.	Monitor organic matter status. Monitor soil recovery after compaction or depletion.
Horticulture	Monitor slowly changing soil properties.	2–5 years	Monitor nutrient status to look for depletion.
Plantation forestry	Monitor soil changes during forest development.	5–10 years, as well as additional sampling immediately after harvest and replanting.	Forest cycles take 20–30 years, with most change occurring around harvest and replanting.
Indigenous vegetation	Acquire information on soils in an unimpacted state.	5–10 years	Get information on what soils were like before development for agriculture and forestry.

Note: For guidance, regions with more than 50 monitoring sites should sample a few of the sites each year to maintain continuity and resampling frequency. Resampling 50 sites might take a 5–10 year cycle.

3 Approaches to monitoring

In this section

This section describes the monitoring approaches that form the basis for the Primary Method and Alternative Method used in the Standard and describes these methods.

3.1 Description of monitoring approaches

Two soil quality monitoring approaches are considered for regional soil quality monitoring across New Zealand and form the basis for this Standard:

- Hill and Sparling (2009) – based on the 500 Soils Project national methodology
- Environment Canterbury Soil Quality Monitoring Programme for Arable and Pastoral Land (Environment Canterbury SQM). This approach only applies to cropping and pastoral land use types.

Both soil quality and trace element monitoring programmes are based on robust methods. In the context of this Standard, the main differences are the:

- coverage of land use types
- sampling field methods
- soil sampling depth.

The current (as at 2017) implementation of soil quality and trace element monitoring by regional authorities is detailed in Annex 1. Of the 16 regional authorities, 12 follow the Hill and Sparling (2009) method, one council (Environment Canterbury) the Environment Canterbury SQM method for arable (cropping) and pastoral land use types, and three councils do not monitor soil quality and trace elements.

Both sets of methods (Hill and Sparling, 2009, and Environment Canterbury SQM) can provide robust data for regional monitoring and national reporting. The Hill and Sparling (2009) set of methods was based on an accepted national approach and subsequently endorsed following review by the Land Monitoring Forum as the primary approach/programme for soil quality and trace element monitoring in New Zealand. As part of the development of this Standard, the Environment Canterbury SQM method was reviewed by the NEMS working group and found to provide suitably robust methods for soil quality and trace element monitoring. The Environment Canterbury SQM method forms the basis of the Alternative Method, but data collected under this approach will not be eligible for QC 600.

Note: Further details on the Environment Canterbury SQM for arable and pastoral land use types is provided in Lawrence-Smith et al. (2010) and Tregurtha et al. (2018).

3.2 Primary and Alternative Methods

The Hill and Sparling (2009) set of methods provides the Primary Method for soil quality and trace element monitoring in New Zealand. The Environment Canterbury SQM set of methods is used by one regional authority for arable (cropping) and pastoral land use types but remains scientifically robust and provides an acceptable Alternative Method for soil quality and trace

element monitoring in New Zealand. The data collected under the Alternative Method will not be eligible for QC 600.

Table 2 outlines the accepted method selection for the Primary and Alternative Methods.

Table 2: The accepted method selection for the Primary Method and the Alternative Method

Component	Primary Method	Alternative Method
Soil quality indicators	Soil chemical pH Total carbon Total nitrogen Olsen phosphorus Soil biological Anaerobic mineralisable nitrogen Soil physical Dry bulk density Air-filled porosity (at -10 kPa) Aggregate stability (for some land uses and where soil has been disturbed, eg, pine harvest, conversion from forest to pasture, erosion events).	Soil chemical pH Total carbon Total nitrogen Olsen phosphorus Soil biological Anaerobic mineralisable nitrogen Soil physical Dry bulk density Air-filled porosity (at -10 kPa) Aggregate stability (for some land uses and where soil has been disturbed, eg, pine harvest, conversion from forest to pasture, erosion events).
Trace elements	arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), fluoride (F), lead (Pb), nickel (Ni) and zinc (Zn)	arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), fluoride (F), lead (Pb), nickel (Ni) and zinc (Zn)
Coverage of land use	All land use types	Cropping and pastoral
Sampling field methods	50 m transect; cores every 2 m at 0–10 cm depth (bulked per transect). Three 10 cm cores, 0–7.5 cm depth (air-filled porosity). Spade sample 0–10 cm depth (aggregate stability). A 20 x 20 cm square and 10 cm deep pit (stony soils only).	Three replicates per site; three soil cores (10 cm diameter) per replicate; 0–15 cm depth, bulked per replicate. One intact soil core (10 cm diameter), 0–7.5 cm depth (air-filled porosity). Spade sample 0–10 cm depth (aggregate stability). A 20 x 20 cm square and 10 cm deep pit (stony soils only).

4 Soil quality indicators

In this section

This section describes the suite of soil quality indicators required for this Standard.

4.1 Required indicators

The suite of soil quality indicators required under this Standard is based on the original 500 Soils Project recommendations, as well as Hill and Sparling (2009) and Cavanagh et al. (2017). The eight soil quality indicators consists of four chemical, one biological and three physical indicators, as outlined in Table 3.

Table 3: The suite of soil quality indicators required under this Standard

Soil quality indicator		Soil quality information provided by indicator	Why is the measure important?
Chemical	Soil pH	Acidity or alkalinity	Most plants and soil animals have an optimum pH range for growth. Indigenous species are generally tolerant of acid conditions but introduced pasture and crop species require a more alkaline soil.
	Total carbon	Organic matter status	Organic matter helps soils retain moisture and nutrients and gives good soil structure for water movement and root growth.
	Total nitrogen	Organic N status	Nitrogen (N) is an essential nutrient for plants and animals. Most N in soil is within the organic matter fraction, and total N gives a measure of those reserves.
	Olsen phosphorus	Plant-available phosphate	Phosphorus (P) is an essential nutrient for plants and animals. Plants get their P from phosphates in soil. Many soils in New Zealand have low available P, and P needs to be added for agricultural use. However, excessive levels can increase loss to waterways, contributing to eutrophication.
Biological	Anaerobic mineralisable nitrogen	Plant-available nitrogen	Not all the organic matter N can be used by plants; soil organisms change the N to forms that plants can use. Anaerobic mineralisable nitrogen gives

			a measure of how much organic N is potentially available to the plants and the activity of the organisms.
Physical	Air-filled porosity (at -10 kPa)	Soil compaction, root environment, aeration, voids	Macropores are important for air penetration into soil and are the first pores to collapse when soil is compacted.
	Dry bulk density (bulk density)	Level of compaction	Compacted soils will not allow water or air to penetrate, do not drain easily, and restrict root growth.
	Aggregate stability	How resistant soil crumbs are to breakage	A stable 'crumbly' texture lets water quickly soak into soil, does not dry out too rapidly, and allows roots to spread easily.

5 Trace elements

In this section

This section describes the suite of trace elements required for this Standard.

5.1 Required trace elements

'Trace elements' refers to the total recoverable soil trace element concentration. The eight trace elements required under this Standard are:

- Arsenic (As)
- Cadmium (Cd)
- Chromium (Cr)
- Copper (Cu)
- Fluoride (F)
- Lead (Pb)
- Nickel (Ni)
- Zinc (Zn)

This suite of trace elements is considered adequate to detect any likely soil contamination in New Zealand, predominantly the result of anthropogenic (management)-based accumulation. Table 4 lists the main sources of the trace elements in soils.

Table 4: Sources of trace elements in soils.

Trace element	Sources
Arsenic (As)	Wood preservatives and alloys
Cadmium (Cd)	Phosphorus-based fertiliser, alloys and batteries
Chromium (Cr)	Wood preservatives, pesticides, alloys and dyes
Copper (Cu)	Copper-based fungicides and pesticides, wood preservatives, paints
Fluoride (F)	Phosphorus-based fertiliser
Lead (Pb)	Lead-based paints and petrol, batteries, metal products
Nickel (Ni)	Alloys and batteries

Zinc (Zn)	Wood preservatives, facial eczema ointments for livestock, car tyre threads, alloys and paints

Note: Other soil quality indicators and trace elements can be added to the soil quality and trace element suites at the discretion of the individual regional authority but are not required for national data federation and do not affect the matrix score and achievement of this Standard.

6 Land use type and soil order classification

In this section

Defining land use type and soil order are critical requirements of this Standard. Correct classification of the land use type and soil order ensure soil quality indicator and trace element data can be interpreted correctly for reporting.

6.1 Land use type

Seven categories of land use type are used: horticulture, cropping, dairy, drystock, exotic forestry, indigenous vegetation and urban open space. The Standard requires that each site be categorised according to one of these land use types. The land use types vary in the breadth of what land uses they include. For example, the land use type 'drystock' is a broad class incorporating many pastoral enterprises, as opposed to 'dairy', which is a much more specific pastoral land use.

A requirement of this Standard is that a site has the following land use type details:

- a land use type classification (which allows national federation of data by land use type), and
- the current land use type at the time of sampling.

A common hierarchical land use type classification provides some guidance for determining land use type. Changes in land use and regional land use differences have necessitated consideration of new land use types and hierarchical classes. These are currently being developed. This Standard requires the use of the seven land use types defined in Table 5.

Table 5. Land use type categories to be assigned to sampling sites under this Standard.

Land use type	Definition
Horticulture	Permanent row orchards and vines.
Cropping	Annual crops, usually grown on a rotational system that can include a short-term (~1-3 years) pasture rotation. Includes maize, barley, wheat, peas, other grain and seed crops, fodder crops and commercial vegetables (includes market gardens).
Dairy	Dairy is the main dairy platform, predominantly used for milking. Dairy may include areas of grazed forage crops and maize for silage.
Drystock (other pasture)	All other (non-dairy platform) pasture, including drystock farms for sheep, beef, deer, goats, horses, dairy support (defined by the absence of a dairy platform) and cut and carry.
Exotic forest	Plantations of exotic tree species grown for pulp and timber production, generally Radiata pine but can include other

	exotic species (eg, redwood, Douglas fir). Usually harvested using clear-felling methods.
Indigenous vegetation	Native forest, tussock, shrubland and scrub dominated by indigenous species. Undisturbed or unfertilised in recent decades.
Urban open space	Open areas of grass in urban areas including parks, school grounds and playgrounds.

Note: Additional guidance for classifying land use type is provided in Hill and Sparling (2009).

6.2 Soil classification

The Standard requires soil classification to soil order using the criteria defined by the New Zealand Soil Classification (Hewitt, 2010). Classifying the soil should be based on the soil profile description and analytical results as required. Classification to subgroup level may also be useful for data interpretation but is not a requirement of the Standard.

7 Timing of sampling

In this section

This section describes the sampling timing required for this Standard. Additional guidance on the timing of sampling for specific land use types is provided.

Under this Standard, the requirements for timing of sampling are:

- All land use types must be sampled in spring (September/October/November) or autumn (March/April/May), but sampling should not coincide with:
  - soil cultivation
  - sowing of crops
  - excessive soil disturbance (eg, from pugging or harvesting)
  - fertiliser additions in previous four weeks
  - very dry or very wet soil conditions.
- Repeat sampling of existing sites must be in the same season as previous sampling at that site (spring or autumn).

There are seasonal and weather-related variables that impact on sample quality. Short-term management effects (eg, harvesting of crops) and safety (eg, avoiding deer paddocks during the roar in autumn) need to be considered.

Ideally, sampling should occur when the soil is moist and clays are swelled to their maximum. Obtaining representative, uncontaminated samples is difficult when soils are excessively dry, frozen, or waterlogged.

Ideal soil moisture conditions for sampling most commonly occur in spring (September/October/November) and autumn (March/April/May). However, soil conditions will vary from year to year, so some judgement is required around the exact time of sampling. Sampling at the same time as previous sampling does not guarantee the same soil conditions.

For **pasture (dairy and drystock) and forestry** sites the preferred sampling time is in spring (September/October/November) but it is permissible in autumn (March/April/May) when the soil is moist and clays are swelled to their maximum.

The preferred sampling time for **cropping** sites is before harvesting when the soil is relatively undisturbed.

Horticultural sites can usually be sampled in spring, but if there are concerns over soil disturbance or excessive compaction by machinery, then sampling should be as for cropping soils (before the harvesting operations are completed).

Some indicators are responsive to short-term management effects. For example, if a site has recently received lime or fertiliser, or has been trampled by stock, the values obtained for pH, Olsen P, bulk density and porosity will not be representative of the 'normal' soil condition (Hill and Sparling, 2009).

At least one month (4 weeks) shall elapse before sampling following an application of fertiliser, or two months if organic fertiliser is used. If such a delay is not practical, then note the site

condition in the field records and interpret the analytical results with caution. These data will not be eligible for QC 600.

Indigenous sites should be sampled in spring or autumn, at the same time as the other land use types are sampled.

To allow assessment of trends over timescales greater than one year, resample sites at the same time of the year as the original sampling.

8 Site selection and at-site considerations

In this section

This section describes selecting new sites, replacing sites, dealing with land use changes at existing sites, and placing sampling transects / sampling layout.

8.1 New sites

Contact the landowners/managers to confirm access to the site and the land use type. An on-site inspection is recommended to confirm the soil order and check for factors that may render the site unsuitable (such as soil disturbance).

Establishing a new site is a substantial investment, so it is important to aim for a good quality, long lasting site. Criteria to be considered when selecting and confirming a site include:

- Are the any problems with access and in removing soil samples?
- Will the site be accessible for future sampling?
- Can information on current use and management be obtained?
- Is the land use history known?
- Are there any planned future changes in land use?

In-paddock objectives when placing the site (and transect) include:

- avoiding disturbed areas in the paddock (eg, gateways, troughs, animal camp areas)
- avoiding uneven topography and variable soil depth
- avoiding multiple soil orders
- ensuring paddock management is spatially consistent where the transect is placed.

8.2 Replacement sites

Where a site is no longer viable for monitoring (eg, landowner no longer wishes to provide access) a replacement site can be selected. Selecting a replacement site should have the same considerations as selecting a new site.

The replacement site should represent the soil order and land use type targeted for the annual monitoring.

Contact the landowners/managers to confirm access to the site and the land use type. An on-site inspection is recommended to confirm the soil order and check for factors that may render the site unsuitable (such as soil disturbance).

8.3 Land use type changes

Where there has been a change in land use type the viability of the site needs to be decided.

The land use type classification can be changed to the new land use type or the site can be removed from the programme (and replaced). In some cases, a site may be useful for monitoring short-term changes during the transition from one land use type to the other.

For the purpose of this Standard, a site's land use type is defined by the current land use at the time of sampling, and details of the length of time in that land use must be recorded (refer to section 9).

8.4 Placing the transect (Primary Method)

Lay out a 50 m transect using a measuring tape. The transect should be on a visually uniform strip, representative of the area to be sampled.

The transect shape should suit the landscape. In more uniform and expansive landscapes, a straight line transect is preferable. In restricted areas, such as orchards and some horticultural sites, shorter transects may be needed. Zig-zag or grid sampling is acceptable, provided the minimum spacing can be maintained and the transect follows the landscape contour. For highly confined sites, an X or W transect of total length 50 m is acceptable. Allow 10 m clearance from any obstruction or disturbed area such as tracks, fence lines, shelter belts, stock camps, water troughs, streams, drainage ditches and buildings.

The transect location must be recorded using a GPS (with the GPS model and accuracy noted) to enable relocation for future samples. Define the start and end of the transect with GPS coordinates or the start point and orientation of the transect (compass bearing recorded in degrees and noting magnetic or true north). Additionally, the location can be sketched onto a detailed aerial photo (at least 1:10,000 scale) or a sketch map that shows the location relative to landmarks such as fences, trees or tracks.

On resampling, the original transect can be offset in the event of changes to the site configuration, eg, due to new fencing or crop layout. The changed positions should be captured using GPS.

8.5 Sample layout (Alternative Method)

A minimum of three sampling locations are identified on a line crossing an area uniform in landform, slope position, soil, land use and management (eg, within a paddock). The sampling locations are typically between 50 m and 150 m apart. The location of the points is captured using GPS. The locations are returned to in future sampling events.

Sampling work is conducted within a ~2 m radius of the identified location.

On resampling, the individual sampling positions can be offset in the event of changes to the site configuration, eg, due to new fencing or crop layout. The changed positions should be captured using GPS.

8.6 Preparation for fieldwork

Field preparation is not a requirement of the Standard. However, sufficient time should be allowed to confirm sites, arrange access with the landowner (including any health and safety requirements), and prepare equipment for site description and sampling.

Note: The availability of sampling equipment, such as sampling cores, may have to be confirmed with the laboratory and collected.

9 Site metadata

In this section

Site metadata are essential for ensuring a site (and transect) can be relocated and resampled. Site description information allows soil quality indicators and trace element data to be interpreted in the context of the land use type, soil order and land management. This section outlines the metadata requirements for site location, site description and land management.

9.1 Site location

Site location details are essential for accurately locating the site and transect location for future sampling. The site data should be detailed enough for a new staff member unfamiliar with the site to be able to relocate the site. GIS-derived maps with the site GPS points and any other details will assist with finding the site location. Navigating to the site is best done using a GPS with the assistance of the maps and any other details. A series of site photos showing the transect can be helpful especially where large background features such as hills are also shown.

The transect location data should be detailed enough for a new staff member unfamiliar with the site to be able to relocate the transect for resampling. A photo of the transect line provides a visual check against the transect GPS points.

A standard form shall be used to record site metadata each time the site is visited for sampling. The form shall include:

- site number
- year of sampling
- year first sampled
- name of person undertaking the sampling, their affiliation
- physical location of site (eg, Fern Farm, Tui Road, Shannon)
- property address
- landowner or manager, their postal address, phone number and email
- local contact person
- map reference
- GPS device used
- GPS of transect start (state projection, eg, NZTM)
- GPS of transect finish (state projection, eg, NZTM) OR transect orientation (compass bearing), and
- transect photo.

9.2 Site description and land management details

Site description and land management details are essential for interpretation of soil quality and trace element data. Soil map information can assist with identifying the soils likely to be present near the site and provide contextual information to support the soil profile description and soil classification.

Land use type and land management details confirm the land use type classification and provide contextual information for interpreting soil quality indicator and trace element data, especially when there are abnormalities in the data.

A standard form shall be used to record the site description details each time the site is visited for sampling. The form shall include:

- soil order (NZSC) – from existing soil map information
- S-map family/sibling; soil series – depending on availability, from existing soil maps
- farm primary system/enterprise (eg. dairy farm)
- sampling site current land use type
- current livestock
- current vegetation
- irrigation
- effluent irrigation
- site land use
- duration of current land use
- slope (degrees)
- elevation (metres above sea level)
- landform (as per Milne et al., 1995)
- mean annual precipitation (based on available rainfall information)
- parent material (based on available geology map information and field verification)
- soil drainage class (as per Milne et al., 1995)
- 'A' horizon (topsoil) thickness (depth)
- total potential rooting depth
- nature of the limiting layer restricting roots
- the nature and date of any extreme events (e.g. flooding, landslips) in the past 5 years
- date of last fertiliser application (type and amount in kg/ha if available).
- date of last cultivation/harvesting/pasture renewal
- date of last grazing, and
- area of bare ground at sampling (% in surrounding 1 ha area).

Note: Not all site description details will vary depending on land use type. For example, effluent irrigation is usually only associated with the dairy land use type. For guidance, two examples of land management history templates (from Hill and Sparling, 2009, and Waikato Regional Council) are provided in Annex 3.

10 Soil characterisation and classification

For all sites, the soil characterisation should include a minimum soil profile description. Ideally, this will be completed at the establishment and first sampling of the soil quality site. Only one soil profile description is required per site. The minimum soil profile description should be completed by, or with direct guidance from, a Suitably Qualified Person (a soil scientist with expertise in pedology).

A soil profile pit or cutting exposure must be dug to provide a minimum soil profile description. The pit or cutting should be located as close as possible to the sampling location but not interfere with the sampling itself. The important consideration is that the soil described is representative of the soil sampled for the site (i.e. the same soil order). Ideally, the soil profile should be 1 m deep (usually into parent material), but a 0.5 m profile is acceptable if supplemented with augering to extend the assessment below 0.5 m. Note that some shallow soils may not be 0.5 m deep. In this situation a soil profile pit/cutting into the C horizon (as defined in Milne et al., 1995) is sufficient. The profile description criteria should conform to Milne et al. (1995) and be classified into the soil order (and group and subgroup if possible) according to Hewitt (2010) to provide categories for stratification. Soil classification is essential to match the site with comparable sites in other regions.

The minimum soil description must include:

- adequate soil characterisation to confirm the soil classification to at least soil order (preferably to soil subgroup)
- the A horizon thickness (depth)
- total potential rooting depth, and
- the nature of the limiting layer restricting the roots (eg, a pan).

A Suitably Qualified Person is a person who has the necessary qualifications and experience to complete the soil profile description in accordance with Milne et al. (1995) and the soil classification in accordance with the New Zealand Soil Classification (Hewitt, 2010).

Note: A freshly cut back soil exposure (cutting) can be used if a soil pit is not practical, but a cutting is not suitable for sampling.

11 Sample collection methods

In this section

This section describes the requirements for collecting and handling field soil samples using either the Primary Method or the Alternative Method.

Note: Clean equipment between samples to minimise contamination.

11.1 Sample details

For all samples collected, the following details shall be recorded in the organisational database and provided with the samples for analysis:

- site number
- sample date, time, depth and location
- sampler's name and organisation, and
- any observations or comments about the sample integrity.

11.2 In-field bulked cores for chemical analyses

The procedure for collecting and storing in-field bulked cores for chemical analysis for the Primary Method is:

1. Collect 25 soil cores at 2 m intervals along the 50 m transect using a 2.5 cm diameter tube auger.
2. The sample depth is 10 cm for the Primary Method.
3. Bulk all cores and seal in a plastic bag.
4. Label the bag using a waterproof marker. Labelling should include the date of sampling, site identification number, land use and the sampler's name.
5. Store the bag in a cool, dark container such as a large chilly bin. Note that a chilled container is not required for transport.
6. Dispatch to the laboratory for analysis as soon as practicable. If storage for more than 1–2 days is needed, store the samples in the dark at 3–5°C (chilled).

Note: For some forest sites the litter material overlying the mineral soil must be cleared before sampling the mineral soil. Milne et al. (1995) provides definitions useful for identifying the litter and the mineral soil.

A 'cup auger' with a fixed 10 cm depth is a useful tool as it allows you to collect several cores in the stainless steel cup, before bagging.

The procedure for collecting and storing in-field bulked cores for chemical analysis for the Alternative Method is:

1. Collect three soil cores at three previously defined locations in the paddock using a 7 cm diameter tube auger.
2. The sample depth is 15 cm for the Alternative Method.

3. Bulk all cores and seal in a plastic bag.
4. Label the bag using a waterproof marker. Labelling should include the date of sampling, site identification number, land use and the sampler's name.
5. Store the bag in a cool, dark container such as a large chilly bin. Note that a chilled container is not required for transport.
6. Dispatch to the laboratory for analysis as soon as practicable. If storage for more than 1–2 days is needed, store the samples in the dark at 3–5°C (chilled).

Note: A sampling depth of 10 cm is favoured as the Primary Method sampling depth (as compared with 15 cm often used for cropping and 7.5 cm for pasture sites) because it is likely to incorporate the topsoil for a range of land use types.

11.3 In-field intact cores for soil physical analysis

The procedure for collecting and storing intact cores for soil physical analysis (air-filled porosity and bulk density) is:

- For the Primary Method, three undisturbed core samples to be taken at either 0 m, 25 m and 50 m or 15 m, 30 m and 45 m along the transect.
- For the Alternative Method, one intact core of 10 cm diameter to a depth of 7.5 cm at each of the three previously defined locations in the paddock.

For both the Primary Method and the Alternative Method, it is important that the structure and fabric of the soil core is disturbed as little as possible to get an accurate measure of porosity and bulk density. Additionally, it is recommended that samples be taken when soil is moist (up to field capacity) as taking samples when soil is either too wet or too dry can result in substandard analyses. This Standard requires sampling using a 7.5 cm long core to protect the central part of the core from physical damage. The laboratory sub-samples a smaller core from this sample. The material used for the core liner can be PVC, aluminium, or stainless steel.

1. Place the core liner (7.5 cm long, 10 cm diameter) on the surface of the soil from which the core sample is to be taken. Press the liner into the soil, push downwards on the ring with a block of wood and cut in.
2. Cut around the outer part of the liner with a sharp knife and continue pressing down until the soil is approximately 0.5 cm below the top of the liner.
3. Carefully dig the liner with intact core of soil out of the surrounding soil, taking care not to break away the soil from the base of the liner.
4. Cut off excess soil below the bottom of the liner using a large spatula or knife.
5. Add a marker label to identify the site and wrap the entire liner and core with self-adhesive plastic film (kitchen wrap).
6. Pack into a padded crate for transport to the laboratory, taking care not to fracture the cores. Dispatch to the laboratory for analysis as soon as practicable. Store the samples at 3–5°C if storage for more than 1–2 days is needed.

11.4 In-field spade samples for aggregate stability

The procedure for collecting in-field spade samples for aggregate stability is:

1. Take triplicate samples for aggregate stability measures from alongside the same transect positions (Primary Method) or paddock sampling locations (Alternative Method) as the soil cores.
2. Cut a vertical block of soil approximately 15 cm x 15 cm square and 10 cm deep from a fresh vertical soil face using a knife and a trenching spade. Avoid smearing and compressing the block.
3. If necessary, take more than one slice; about 500 g of the 2–4 mm fraction is needed for the wet sieving test.
4. Place the slice into a strong plastic bag or container, seal and label with site identification. If necessary, samples should be stored at 3–5°C until analysis.

11.5 Fine-earth fraction bulk density and stone content for stony soils

Stony soils are problematic to sample, particularly when trying to collect intact cores for soil physical analyses and when making soil bulk density determinations. If intact cores cannot be obtained because the soil is too stony, then the following procedure should be used.

The method relies on digging a pit to the required depth, calculating the volume, and weighing the excavated contents. You will need:

- a balance capable of weighing 10 kg (a spring balance is suitable)
- plastic sheeting
- a 10 mm screen for sieving, and
- a bucketful of suitable uniform material for backfilling (eg, dry sand, beads, tapioca or similar).

The volume of the excavated pit is calculated by measuring its dimensions, or by backfilling and weighing the mass of backfill material, as explained below.

1. At each of three locations within each site, preferably where the intact cores were to be collected, dig a rectangular pit approximately 20 x 20 cm square and 10 cm deep.
2. Sieve the excavated soil through a 10 mm sieve and record the weight of stones remaining on the sieve (a bucket is handy for this).
3. Weigh the sieved material then mix and bag a 200–500 g subsample for later analysis in the laboratory.
4. If the form is sufficiently regular, calculate the volume of the pit by careful measuring. In cases where large stones have caused an irregular form, line the pit with a thin plastic sheet and backfill with dry sand, plastic chips or other suitable material. Lighter materials are useful if the site is not easily accessible with a vehicle. You will need to know the volume occupied by a known weight of your chosen backfill material. If more convenient, the plastic-

lined pit can be filled with water (provided it is level). Record the weight of dry backfilling material needed to fill the pit.

5. In the laboratory, weigh the subsample and sieve through a 2 mm sieve to remove any stones, then record the weight of the stones.
6. Measure the water content of the sieved material and calculate the fine earth fraction bulk density and stone content for each location.

If required, the fine material separated from the stones can then be repacked to its original density into soil physics rings and used to characterise the porosity and moisture characteristics of that fraction. The data will not be as reliable or interpretable as that obtained from intact cores because of the various manipulations.

Note: For practical reasons it may be necessary to restrict soil physical measurements on stony soils to bulk density determinations only and rely on the soil profile description to deduce whether there is soil compaction.

11.6 Chain of Custody

A competed form with details of sampling is to accompany the samples. The form requires the following information for the laboratory staff: regional authority, contact person, contact phone, contact email, site number, land use, general topography, general location, date sampled, ring 1 number(s), and comments.

If more than one chilly bin is dispatched, either place a copy of the chain of custody form into each bin or include a waterproof note confirming the number of chilly bins dispatched.

For chain of custody signoff, it should be requested that confirmation be given of sample receipt (including that bulk sample bags match site list and that the appropriate number of rings have been received).

12 Laboratory accreditation

In this section

This section outlines laboratory certifications used in New Zealand and the requirements for laboratory accreditation in this Standard.

A desirable New Zealand standard for the laboratory to have attained is NZS ISO/IEC 17025. Many laboratories have ISO 9002 registration, but this is of less value. ISO 9002 registration only shows that procedures are documented and registration itself is not a guarantee of analytical accuracy.

Under this Standard, soil samples should be tested at a laboratory accredited by International Accreditation New Zealand (IANZ) for each analytical method to ensure that the laboratory has appropriate quality practices in place to produce reliable results.

IANZ is an independent organisation that operates under its own Act of Parliament and audits laboratories against NZS ISO/IEC 17025. An experienced auditor accompanied by one or more technical experts from IANZ visits accredited laboratories. The IANZ representative audits laboratory management, documentation, staff training, calibration of equipment, internal audits, etc. The technical expert audits laboratory methods and ensures that the staff carrying out the testing are following the documented test procedure and are knowledgeable about what they are doing.

Further information about IANZ can befound at www.ianz.govt.nz .The accreditation status of each laboratory and their analytical methods can be found under the *Directory* tab.

If an alternative certification for laboratories is available (eg, Australasian Soil and Plant Analysis Council Incorporated (ASPAC) certification), it can provide an acceptable equivalent for the purposes of this Standard.

For all soil quality and trace element data, certification documentation and detailed documentation of the analytical methods are required.

13 Laboratory analysis

In this section

This section focuses on activities undertaken in the laboratory. It addresses laboratory sample preparation (drying and sieving), analytical methods, relevant calculations, reporting units, and quality control. For many variables, there are multiple analytical methods available, or the same methods can have slight variations across laboratories.

For the purposes of this Standard the method(s) specified have been determined as the most appropriate for long-term soil quality monitoring. Most of the methods listed are standard methods; however, slight variations across different laboratories are inevitable and acceptable.

This Standard requires all analytical methods to be documented and any modifications to analytical methods to be clearly identified. The default detection limits used by the laboratory shall be recorded.

The Standard recognises that methods need to be periodically reviewed, as more precise measurements and new methods may become available as technology advances.

Some guiding principles for selecting analytical laboratories and methods are:

- The laboratory shall hold current IANZ accreditation (or an alternative equivalent) for the method (see section 12). This means that the laboratory has been independently certified to perform the required analysis(es).
- Consistency in method is important, especially if data are to be compared against historic data or with data from another programme. At the very least, the basic chemistry used for analysis should not be changed except for a compelling reason; for example, a much cheaper test is developed. Even so, the new method must be calibrated against the existing method so data with the modified method can be compared with previous data.
- It is essential that all methods used are standardised and documented; soils are monitored over time and it is important that current data can be compared with archival data. Laboratories should be able to confirm methods annually.

The Standard accepts some minor variations from the exact methods prescribed. These variations are likely across laboratories and are largely because of sample handling and analytical equipment used in each laboratory (eg, automated analysis vs manual analysis).

13.1 Soil preparation for chemical analyses

The 25 individual cores from the transect are bulked and mixed before analysis. Any adhering vegetation, roots, macrofauna or stones should be discarded. If soil needs to be dried (eg, from waterlogged sites) to permit handling, then a cold air fan with continual mixing of the soil is recommended or the soil should be spread and frequently mixed on trays in a cold-room. In either case, the intention is to avoid any heating or localised rapid drying of the soil. Storage of moist soil for extended periods is not recommended as there will be a change in soil properties. If necessary, moist soil should be stored in loosely sealed polyethylene bags at 5°C. Moist soil is used for the

anaerobic mineralisable nitrogen test; dried soil is used for the other chemical measurements. Once air-dried the soil can be stored in sealed containers at room temperature.

13.1.1 Drying and grinding

Samples are dried as soon as they arrive at the laboratory to minimise biological transformations and other chemical reactions. Once the sample has been dried, the sample should be homogenised. If the sample size is too large, it should be reduced by coning and quartering. Plant and root material are removed by hand then the samples are dried in a forced-air convection drier at 25–40°C (35°C is the common temperature used for air-drying). The drying time depends on factors such as sample size, moisture content, texture and organic matter content.

Large rock fragments are removed before the sample is ground in a roller grinder to pass through a 2 mm sieve. Samples should be ground in a way that avoids element contamination (eg, using a mortar and pestle). Note that mills can contaminate a sample with trace elements, eg, tungsten from tungsten carbide ring mills, and therefore mills must not be made of materials that would contaminate the trace element suite. The ground soil is mixed and a subsample taken for analysis. For methods that require a small sample weight (< 1.0 g) a subsample is taken from the < 2 mm portion and further ground in a ring mill to < 0.25 mm. In some cases, air-drying changes soil properties to such an extent that field-moist samples are used instead, eg, for analysis of anaerobic mineralisable nitrogen.

13.1.2 Moisture content method

Most soil chemical and biochemical analyses are carried out on air-dry samples as oven drying at 105°C causes irreversible changes. Alternatively, some analyses need to be carried out on field-moist samples or samples that have been wetted until they achieve a moisture tension. Irrespective of moisture conditions for individual analyses, all results must be reported on an oven-dry weight basis.

13.1.3 Drying procedure

1. Weigh a labelled aluminium or glass dish with lid and record the weight (w1).
2. Add approximately 5 g of soil sample into the dish and record weight (w2).
3. Dry at 105°C for 8–24 hours (overnight) to a constant weight.
4. Remove from oven, fit lid, cool and reweigh (w3).

Note: Because oven-dry soil rapidly picks up water vapour from the atmosphere (even in some desiccators), it is necessary to reweigh as soon as the dish is cool enough to handle but before it cools to room temperature. Place samples in a desiccator to cool. Note that a slight air gap should be left to allow heated air (that expands) to escape and air pressure to equilibrate as samples cool (otherwise you will not be able to open the desiccator, unless it has a built-in air valve). Record all weights to three significant figures.

13.1.4 Calculation of moisture factor

$$\textbf{Moisture Content (\%MC)} = (w_2 - w_3) / (w_3 - w_1) \times 100$$

where: w_1 = weight of tin (or dish), w_2 = weight of tin + fresh soil, w_3 = weight of tin + oven-dried soil

Moisture Factor (MF) = 1+ (%MC/100)

Converting analyses to an oven-dry weight basis when results are presented on a fresh or air-dried weight basis:

Oven-dry weight (g) = Air-dried weight (g) x MF

13.1.5 Stone content

The content of stones is determined from excavating material from a pit 20 x 20 cm to a depth of 10 cm (refer to section 11.5). The volume of the pit is determined by backfilling with a product of consistent fill density. The extracted material is sieved at 10 mm and sorted into stones, root material and < 10 mm material, a subsample of which is further sieved at 2 mm to calculate the proportion of stones > 2 mm extracted from the pit.

13.2 Dry bulk density

Dry bulk density (bulk density) gives an indication of whether a soil is loose or compacted and provides a factor to convert any soil properties measured on a weight basis to a volume equivalent. Bulk density measurements can be conveniently combined with moisture release characteristics to measure porosity and available water. Intact cores or soil blocks are needed but a subsample may be used to determine dry bulk density. Record the volume of soil used to three decimal places.

To calculate bulk density:

Bulk density (g/cm^3) = Oven-dry weight (g) / volume of soil (cm^3).

Note: Dry bulk density (bulk density) is sometimes referred to as fine-earth bulk density.

13.3 Air-filled porosity (at -10 kPa)

Note: Intact soil cores are required for these measurements.

In a general sense, macropores refer to the larger pores that are the main route by which air enters soil. They are the first pores to be lost when soil is compacted. In the literature the size range for defining macropores varies between 30 and 3000 µm.

Under this Standard, a tension of –10 kPa is used to calculate air-filled porosity, which corresponds to a pore size of around 30 µm.

Note: There has historically been some confusion over terminology, with the term 'macroporosity' being most commonly used in place of the term 'air-filled porosity'. Furthermore, a –5 kPa tension was initially used to calculate the macroporosity indicator for early (pre-2003) soil quality data and some organisations subsequently used –5 kPa tensions to calculate air-filled porosity; care should be taken to ensure the correct tension has been used.

The New Zealand Soil Bureau technically defined macroporosity as [total porosity – (volumetric water content at –5 kPa)], whereas air-filled porosity was technically defined as [total porosity – (volumetric water content at –10 kPa)].

The Land Monitoring Forum decided that a tension of –10 kPa, corresponding to a pore size of around 30 µm, would be used and that the term air-filled porosity would be used in place of the previously used macroporosity term. Thus, the air-filled porosity measure defined by the New Zealand Soil Bureau corresponds to the air-filled porosity indicator in this Standard.

Air-filled porosity (soil pores > 30 µm in diameter) is measured on tension tables at -10 kPa and refers to the volumetric proportion of macropores in the soil (%v/v).

To calculate air-filled porosity, it is necessary to know the bulk density, particle density, and volumetric water content at –10 kPa. Bulk density and particle density are first used to calculate total porosity:

Total Porosity (%) = (1 - (Bulk density / Particle density)) x 100

Then to calculate air-filled porosity:

Air-filled porosity (%) = Total Porosity - (volumetric water content at -10 kPa)

13.4 Aggregate stability

Aggregates of 2 to 4 mm diameter are separated from the whole soil by non-forced sieving and then air-dried at 25°C, before determining aggregate stability using a wet-sieving method (Kemper and Rosenau, 1986). The air-dried 2 to 4 mm aggregates (50 g) are sieved under water for 20 min on a nest of sieves (2.0, 1.0 and 0.5 mm diameter). The soil remaining on each sieve is weighed after oven drying at 105°C. The weight of material remaining on each sieve is corrected for stone content. The aggregate stability is expressed as a mean weight diameter (MWD) in mm:

$$MWD = \sum_{i=1}^{n} x_i w_i$$

where X_i is the mean diameter of i adjacent sieves and W_i is the proportion of the total sample retained on a sieve.

13.5 Total carbon (C) and total nitrogen (N)

Each subsample of air-dried soil for total carbon (C) and total nitrogen (N) analysis is mixed thoroughly. Total C and total N are determined by Dumas dry combustion of 0.5 g soil samples at 1250°C on an industry-accepted elemental analyser (eg, LECO TruMac CN analyser, Lachat QuikChem 8500 Series 2 Flow Injection Analysis System).

13.6 Anaerobic mineralisable nitrogen (AMN)

The analytical results for AMN are known to vary depending on whether a field-moist or air-dry sample is used. Both methods are acceptable in this Standard. However, whether a field-moist or air-dry sample was used must be recorded, along with the analytical method used.

Anaerobic mineralisable nitrogen is measured by the change in the extractable ammonium-N after anaerobic (waterlogged) incubation (seven days at 40°C) using 5 g of field-moist or air-dry, sieved soil and potassium chloride (KCl) extraction. Ammonium and nitrate-N in the extracts are measured on an industry-accepted elemental analyser (eg, LECO TruMac CN analyser, Lachat QuikChem 8500 Series 2 Flow Injection Analysis System).

13.7 Soil pH

Soil pH is determined by glass electrode from a suspension of 1 part soil (air-dried; < 4 mm) to 2.5 parts distilled water, stirred, and then left to stand for 16 hours.

13.8 Olsen phosphorus (Olsen P)

The Olsen P indicator is a measure of available P in the soil. It follows the procedure of Brookes et al. (1982) and is based on the method of Olsen et al. (1954) which uses an extraction with bicarbonate to estimate the plant-available phosphorus in soil (commonly referred to as Olsen P). Olsen P is measured following extraction of 2 g of air-dry soil in 40 mL of 0.5 N sodium bicarbonate ($NaHCO_3$) (solution buffered to pH 8.50 ± 0.05) at 25°C with end-over-end tumbling for 30 min. The extracts are centrifuged immediately after tumbling and/or filtered through pre-leached filter papers. Extracts are analysed for orthophosphate on an industry-accepted elemental analyser (eg, LECO TruMac CN analyser, Lachat QuikChem 8500 Series 2 Flow Injection Analysis System).

13.9 Arsenic, cadmium, chromium, copper, lead, nickel and zinc

Soil samples are air-dried at 25–35°C and subsequently ground to < 250 µm. Soil samples are digested in hydrochloric (using 3437% concentration reagent grade minimum)[3] and nitric acid (using 6770% concentration reagent grade minimum)[4]. Total recoverable concentrations are determined in the digest by ICP-MS or a similarly accurate instrument or determination (eg, graphite furnace, classic wet chemistry, hydride generation that meets the accepted detection limits and precision). Also, zinc can be accurately determined by AAS and ICP-OES.

13.10 Fluoride

Determination of total F in soil samples is by the alkaline fusion/ion-selective electrode method.

[3] Based on US EPA 200.2
[4] Based on US EPA 200.2

13.11 Reporting units

Laboratories are required to provide data using the reporting units listed in Table 6 or with the ability to correct for the units required. Note that soil chemistry data can be provided by the laboratory on a gravimetric or volumetric basis and this needs to be noted. Chemical data can be converted from a volumetric basis to a gravimetric basis using the laboratory volume weight.

Results for trace elements are typically reported in units of mg/kg. The required soil quality indicator and trace element units are shown in Table 6.

Table 6. Soil quality indicator and trace element units for reporting

Soil indicators	**Reporting units**
Soil pH	pH units
Olsen phosphorus	mg/kg*
Total carbon	w/w
Total nitrogen	w/w
Anaerobic mineralisable nitrogen	mg/kg
Dry fine bulk density	g/cm^3
Air-filled porosity (at -10 kPa)	%, v/v
Aggregate stability (mean weight diameter)	mm
Trace elements	
Total recoverable arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), fluoride (F), lead (Pb), nickel (Ni) and zinc (Zn)	mg/kg

* Alternatively, if Olsen P is reported in mg/L then mg/kg can be approximated using the laboratory volume weight for conversion.

13.12 Sample management

Laboratories are to manage physical samples as per accreditation requirements, to minimise the occurrence of sample loss, mix ups, deterioration and destruction. Site samples are a valuable resource for associated research. Remaining samples should be retained for archiving.

Procedures for dealing with multiple and damaged samples need to be consistent to maintain data integrity. The provision of data from the laboratory should avoid the occurrence of introduced error.

13.12.1 Replicate samples

If replicates are collected (eg, three cores collected for soil physical analysis) then the results for each sample should be recorded in the database and the values averaged to determine a single soil quality indicator value. All three values should be used unless a sample has earlier been excluded from analysis or the data are considered compromised.

Exclusion of a sample for analysis will be at the discretion of the laboratory. Exclusion will be only if analysis cannot be physically completed for that sample. If excluded, then the sample number and reason for exclusion needs to be recorded. Any subsequent exclusion of sample data will be at the discretion of the monitoring agency staff member responsible for soil quality indicator and trace element data in the year of sampling.

The data from the analysis of at least two samples must be used.

13.12.2 Sample archiving

A physical sample of the soil should be archived for possible future reanalysis. The laboratory should retain and return a physical soil subsample for archiving. The soil subsample should be at least 250 g and drawn from the air-dried < 2 mm fraction of the soil remaining from the soil analyses. Physical samples should be stored in screw-top containers (glass or plastic), at 18–25°C (room temperature) and clearly labelled with a unique site identifier and sampling date.

13.12.3 Laboratory results

Laboratories are required to provide analysis results in electronic format and, if possible, directly uploaded to the monitoring agency's database.

14 Data management

In this section

This section outlines the requirements for data management including data preservation and storage. Upon publication of this document, an Annex to the Data Processing NEMS will be developed for soil quality and trace element data.

14.1 Data preservation and storage

All data and metadata shall be stored in organisational databases and linked with a unique identifier code. A link to the following records should also be considered:

- site metadata (including site, land management, laboratory methods and geospatial data)
- quality assurance, and
- any legal requirements, confidentiality agreements and/or restrictions related to data access.

All original hard copy (or scanned copies) and electronic records shall be retained indefinitely by the monitoring agency.

14.2 Quality codes

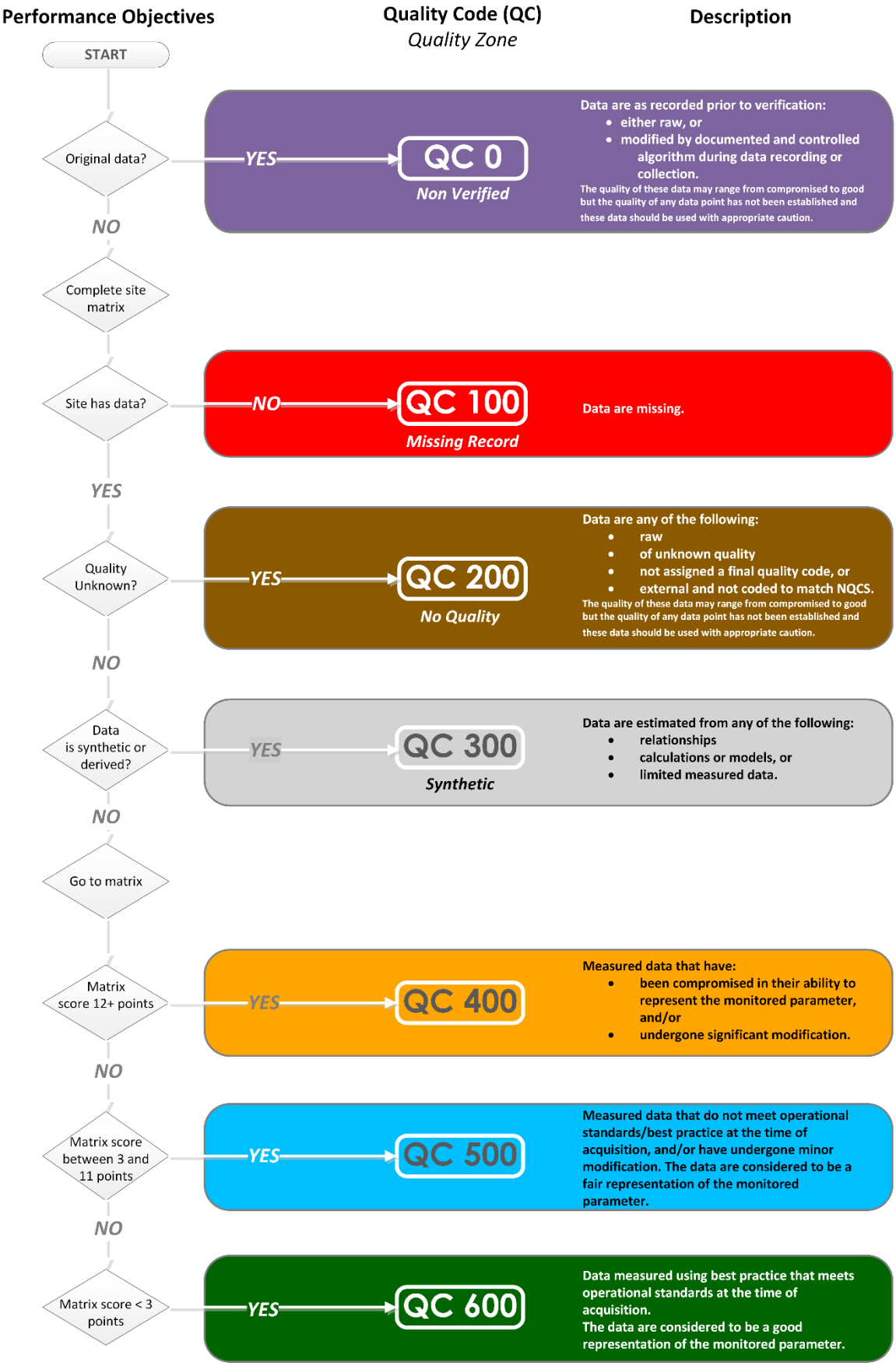
All data shall be quality coded in accordance with the NEMS *Quality Code Schema*. The schema permits valid comparisons within and across multiple data series. Use the following flowchart to assign quality codes to soil quality and trace element data.

Any field or laboratory measurement data that do not meet this Standard shall be assigned a quality code from QC 100 to QC 500.

Note: A quality code of QC 600 shall only be assigned where this Standard and associated best practice is achieved. In most cases, soil quality and trace element data collected as part of long-term (eg, SoE) monitoring will fall under one of QC 400, QC 500 or QC 600. The Quality Code is assigned using 'demerit' points:

QC 600	<3 points
QC 500	3–11 points
QC 400	>11 points

The demerit points are calculated using the Soil Quality and Trace Element Matrix.


Performance Objectives
Quality Code (QC)
Quality Zone
Description
START
Original data?
YES
QC 0
Non Verified
Data are as recorded prior to verification:
either raw, or
modified by documented and controlled algorithm during data recording or collection.
The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.
NO
Complete site matrix
Site has data?
NO
QC 100
Missing Record
Data are missing.
YES
Quality Unknown?
YES
QC 200
No Quality
Data are any of the following:
raw
of unknown quality
not assigned a final quality code, or
external and not coded to match NQCS.
The quality of these data may range from compromised to good but the quality of any data point has not been established and these data should be used with appropriate caution.
NO
Data is synthetic or derived?
YES
QC 300
Synthetic
Data are estimated from any of the following:
relationships
calculations or models, or
limited measured data.
NO
Go to matrix
Matrix score 12+ points
YES
QC 400
Measured data that have:
been compromised in their ability to represent the monitored parameter, and/or
undergone significant modification.
NO
Matrix score between 3 and 11 points
YES
QC 500
Measured data that do not meet operational standards/best practice at the time of acquisition, and/or have undergone minor modification. The data are considered to be a fair representation of the monitored parameter.
NO
Matrix score < 3 points
YES
QC 600
Data measured using best practice that meets operational standards at the time of acquisition.
The data are considered to be a good representation of the monitored parameter.

Soil Quality and Trace Element Matrix

When assigning a quality code to data for a site, first calculate the total demerit points using the following matrix:

Criteria	12 points	3 points	1 point	0 points
Soil quality indicators	Includes some of the suite of soil quality indicators, with more than 3 missing or different.	Includes most of the suite of soil quality indicators, with up to 3 missing or different.	Includes most of the suite of soil quality indicators, with up to 1 missing or different.	Includes the full suite of soil quality indicators (including aggregate stability for applicable land use types).
Trace elements	Includes some of the suite of trace elements, with more than 4 missing.	Includes most of the suite of trace elements, with up to 4 missing.	Includes most of the suite of trace elements, with up to 2 missing.	Includes the full suite of trace elements.
Timing of sampling	Sampling of site is not at correct time of year (spring or autumn); or resampling of site is not in the correct season and is not in the same season as originally sampled; or sampling is when the conditions are unsuitable or does not avoid management events.	Sampling of site is not in the correct season (spring or autumn); site sampled when the conditions are suitable, avoiding management events.	Resampling of site is in the correct season (spring or autumn) but the resampling of site is not in the same season as originally sampled (spring or autumn); site sampled when the conditions are suitable, avoiding management events.	Sampling of site is in the correct season (spring or autumn) or resampling of site is in the correct season and same season as originally sampled (spring or autumn); site sampled when the conditions are suitable, avoiding management events.

Criteria	12 points	3 points	1 point	0 points
Site location data	The site has a map location but no GPS location or transect start and finish points; minimal other site description details apart from site property address and property contact details.	The site has a map location but minimal GPS transect location details (eg, a point on a map), minimal other site description details apart from site property address and property contact details.	The site has a map location but minimal GPS transect location details (eg, a point on a map), site location photos, site property address, property contact details.	The site has a GPS location, transect start point and end point (or direction), site location photos, site property address, property contact details.
Site description	The site description has not been completed. No land management history.	Site description has been completed. No land management history.	Site description has been completed. Land management history has been partially completed.	Site description has fully completed. Land management history has been completed.
Soil characterisation and classification	A minimum soil profile description has not been completed (including a partial description) and soil order is not estimated from existing soil map information.	A minimum soil profile description has not been completed (including a partial description) and soil order is estimated from existing soil map information.	-	A minimum soil profile description has been completed by a Suitably Qualified Person and can confirm the soil order.

Criteria	12 points	3 points	1 point	0 points
Sample field collection	Neither the Primary Method nor the Alternative Method is used; other in-field sampling methods are used for sampling.	The Alternative Method is used for pasture and cropping sites.	The Primary Method is used, with minor variations that are unlikely to affect the data.	The Primary Method is used for the site.
Sample field management	Samples are poorly labelled, and storage and transportation requirements are not followed.			All samples are clearly labelled, and storage and transportation requirements are followed.
Laboratory certification	Laboratory does not hold IANZ (or similar) and is not able to provide evidence of observing standard procedures and quality assurance/quality control practices for the measurement methods.	Laboratory holds documentation for the measurement method and incorporates quality assurance/quality control practices but lacks current IANZ (or similar) certification where available.		Laboratory holds documentation for the measurement method and incorporates quality assurance/quality control practices and provides documentation for current IANZ (or similar) certification where available.
Laboratory analyses	The methods vary substantially from the	The required methods (as specified in the Standard) are mostly followed with some variation from the	The required methods (as specified in the Standard) are confirmed and followed (ie, followed with some minor	The required methods (as specified in the Standard) are confirmed and followed (ie, followed with some

Criteria	12 points	3 points	1 point	0 points
	methods specified in the Standard.	required methods, likely to have a minor impact on data quality.	variations but methods are accepted). Laboratories cannot provide documentation to confirm methods.	minor variations but methods are accepted). Laboratories can provide documentation to confirm methods.
Data management	Data are recorded and entered directly into a non-organisational spreadsheet; data are not backed up.		Data are recorded on required forms (where provided); data are entered into a non-organisational spreadsheet; data are backed up.	Data are recorded on required forms (where provided); spatial and non-spatial data are entered directly into organisational databases; data are backed up.

Annex A – List of Referenced Documents

Brookes PC, Powlson DS, Jenkinson DS. 1982. Measurement of microbial biomass phosphorus in soil. *Soil biology and biochemistry* 14: 319-329.

Cavanagh J, Munir K, McNeill S, Stevenson B. 2017. *Review of soil quality and trace element State of the Environment monitoring programmes*. Envirolink Advice Grant: 1757-HBRC226. Landcare Research, Palmerston North.

Giltrap DJ, Hewitt AE. 2004. Spatial variability of soil quality indicators in New Zealand soils and land uses, *New Zealand Journal of Agricultural Research*, 47(2): 167-177.

Haynes RJ, Tregurtha R. 1999. Effects of increasing periods under intensive arable vegetable production on biological, chemical and physical indices of soil quality. *Biology and Fertility of Soils* 28: 259-266.

Hewitt AE. 2010. *New Zealand Soil Classification*. Landcare Research Science Series No.1, 3rd edition. Manaaki Whenua Press, Lincoln, New Zealand.

Hill RB, Sparling G. 2009. "Soil quality monitoring." In: *Land and Soil Monitoring: A guide for SoE and Regional Council Reporting*. Land Monitoring Forum, New Zealand.

Hill RB, Sparling G, Frampton C, Cuff J. 2003. *National Soil Quality Review and Programme Design.* Technical Paper 75, Land. Ministry for the Environment, Wellington.

Jones H, Drewry J, Burton A, Burgess D, Wyatt J. 2015. *Knowing our land: a review of land and soil state of the environment monitoring and reporting in New Zealand*. Scoping report of the Environmental Monitoring and Reporting (EMaR) Land project. Waikato Regional Council, Hamilton.

Keeney DR, Bremner JM. 1966. Characterization of Mineralizable Nitrogen in Soils. *Soil Science Society of America Journal* 30(6): 714–719.

Kemper WD, Rosenau RC. 1986. Aggregate stability and size distribution. In: A Klute (ed.) *Methods of soil analysis. Part 1 – Physical and mineralogical methods*. Second edition. Soil Science Society of America, Madison, Wisconsin.

Kim N, Taylor M. 2009. "Trace element monitoring." In: *Land and Soil Monitoring: A guide for SoE and regional council reporting*. Land Monitoring Forum, New Zealand.

Lawrence-Smith EJ, Tregurtha CS, Meenken ED. 2010. *Regional environmental monitoring programme for soil quality 2009–10: Arable and Pastoral Project Final Report*. A Plant & Food Research report prepared for Environment Canterbury.

McQuaker NR, Gurney M. 1977. Determination of total fluoride in soil and vegetation using an alkali fusion-selective ion electrode technique. *Analytical Chemistry* 49: 53–56.

Milne JDG, Clayden B, Singleton PL, Wilson AD. 1995. *Soil Description Handbook*. Manaaki Whenua Press, Lincoln, Canterbury, New Zealand.

Olsen S, Cole C, Watanabe F, Dean L. 1954. *Estimation of available phosphorus in soils by extraction with sodium bicarbonate.* USDA Circular No 939. US Department of Agriculture, Washington.

Parliamentary Commissioner for the Environment. 2019. *Focusing Aotearoa New Zealand's environmental reporting system.* Parliamentary Commissioner for the Environment, Wellington.

Parshotam A, Hewitt AE. 1995. Application of the Rothamsted carbon turnover model to soils in degraded semi-arid land in New Zealand. *Environment International* 21: 693-697.

Sparling G, Schipper L. 2004. Soil quality monitoring in New Zealand: trends and issues arising from a broad-scale survey. *Agriculture, Ecosystems and Environment* 104: 545-552.

Sparling GP, Rijkse W, Wilde RH, van der Weerden T, Beare MH. 2001a. *Implementing soil quality indicators for land: Research report for 1999/2000*. Unpublished Landcare Research Contract Report 0001/059. Hamilton, Landcare Research.

Sparling GP, Rijkse W, Wilde RH, van der Weerden T, Beare MH, Francis GS. 2001b. *Implementing soil quality indicators for land: Research report for 2000/2001 and final report for MfE Project Number 5089*. Landcare Research Contract Report LC0102/015. Hamilton, Landcare Research.

Sparling GS, Rijkse W, Wilde H, van der Weerden TJ, Beare MH, Francis GS. 2000. *Implementing soil quality indicators for land: Research Report for 1998/1999*. Landcare Research Contract Report: 9900/108, Hamilton, Landcare Research.

Sparling GP, Searle PL. 1993. Dimethyl sulphoxide reduction as a sensitive indicator of microbial activity in soil: The relationship with microbial biomass and mineralization of nitrogen and sulphur. *Soil Biology and Biochemistry* 25: 251–256.

Stevenson B, McNeill S, Hewitt A. 2012. *Utilising the soil quality monitoring data set: multivariate and spatial analysis of soil quality data*. Landcare Research contract report LC1060. Landcare Research.

Tregurtha CS, Lawrence-Smith EL, Gosden ML. 2018. Regional environmental monitoring programme for soil quality 2017–18: Arable and Pastoral Monitoring Programme – final report. A Plant & Food Research report prepared for Environment Canterbury.

Annex 2: Regional monitoring programme summary

Summary of regional authority soil quality and trace element monitoring sites, indicators, and sampling frequency as of 2017 (based on Cavanagh et al., 2017).				
Regional /unitary authority	**Number of sites**	**Frequency of site sampling (years)**	**[1]Seven soil quality indicators (+ aggregate stability)**	**Trace elements As, Cr, Cu, Pb, Ni, Zn (+ Cd, F)**
Northland	29	5	Y	Y (+ Cd)
Auckland	124	3-10	Y	Y (+ Cd)
Waikato	156	5	Y (+ Aggr. Stab.)	Y (+ Cd, F)
Bay of Plenty	82	3-10	Y	Y (+ Cd, F)
Hawke's Bay	86	3-5	Y	Y (+ Cd, F)
Gisborne	50[2]	5	-	-
Taranaki	20	5	Y (+ Aggr. Stab.)	Y (+ Cd)
Horizons (Manawatu-Wanganui)	41	5[3]	Y (+ Aggr. Stab.)	Y (+ Cd)
Wellington	118	3-10	Y (+ Aggr. Stab.)	Y (+ Cd, F)
Tasman	35	10[4]	Y (+ Aggr. Stab.)	Y (+ Cd, F)
Marlborough	92	5	Y	Y (+ Cd, F)
Nelson	15	5	Y[5]	Y (+ Cd, F)
Canterbury	314	8-9	Y (+ Aggr. Stab.)	Y (+ Cd)
West Coast	0	-	-	-
Otago	0	-	-	-
Southland	57	8-10[6]	Y	Y (+ Cd, F)

[1] Seven soil quality indicators: pH, Olsen P, total carbon, total nitrogen, anaerobic mineralisable nitrogen, bulk density and air-filled porosity.

[2] Not yet commenced.

[3] Sampled once; likely frequency.

[4] Sampled once; likely frequency.

[5] No cropping sites in Nelson unitary authority area.

[6] Sampled once; likely frequency.

Annex 3: Equipment lists

Equipment required for field sampling:

- Spade
- Trowel
- Knife
- Hammer
- Block of wood
- Auger (for characterisation work)
- Soil core sampler 0–10 cm
- Core rings (ideally stainless steel, 10 cm diameter and 7.5 cm long, pre-weighed and uniquely numbered)
- Labels (on waterproof paper)
- Plastic bags (multiple sizes, pre-labelled with waterproof paper labels inside)
- Permanent ink marker
- Wash down water
- Tape measure (50 m)
- Black plastic ground sheet
- Camera
- Notebook and pencil/pen
- Plastic film wrap
- GPS
- Maps
- Landowner and location spreadsheet
- Chilly bins
- Aggregate stability sampling container (2 L)
- Fill material (eg, dry sand, beads, tapioca or similar) for use in 'stony soil' bulk density work. Used to backfill sample pit to determine volume
- Measuring container (used to determine volume of fill material)

Soil description list:

- Munsell colour book
- Tape measure (5 m)
- Water spray bottle
- Soil description sheets (paper or electronic) following Milne et al. (1995)

Annex 4: Land management history templates[5]

Template for site management history

Soil Quality Monitoring

Contact and Land Use Description Check Sheet

Sample number ..... Sampled by .....

Date .....

Location .....

Accompanied by map/photo/sketch plan plus summary sheet)

Landowner

Occupier Yes ☐ No ☐

If No is occupier Manager ☐ Sharemilker ☐ Lessee ☐

Is landowner contact person? Yes ☐ No ☐

Landowner name _____

Property address _____

_____

_____

Landowner postal address _____

_____

_____

_____

Landowner Phone _____

Fax _____

Email _____

Occupier

Is occupier contact person? Yes ☐ No ☐

Occupier name _____

Address (residential/postal) _____

_____

_____

Occupier Phone .....

[5] Hill and Sparling (2009) and Waikato Regional Council templates.

Fax _____

Email _____

Contact person

Contact name _____

Address (residential/postal) _____

_____

_____

Contact Phone _____

Fax _____

Email _____

Current Land Use Details

Present Land Use

_____

_____

Description of management type/approach

_____

_____

_____

Duration of present land use _____

Vegetation cover dominant _____

secondary/sub-dominant _____

Crop/stock type _____

Crop/stocking rates _____

Age of crop/pasture _____

Irrigation Yes ☐ No ☐ annual depth .....

Effluent application Yes ☐ No ☐

type, frequency, rate etc .....

_____

Crop rotation sequence/grazing system

_____

_____

Artificial drainage Yes ☐ No ☐

Sequence of land uses with approx. dates (or best guess) including fertiliser history (if known)

Waikato Regional Council Soil Quality Monitoring Contact Details and Land Information template

Who do we contact?.....

Phone number(s)……

Email address……

Address to send results to……

……

Present land use……

Duration of present land use……..

Historic land use and duration if known……

……

……

Crop/Stock type……..……

Crop/Stocking rates……..

Age of crop/pasture..……...

Frequency of cultivation……

Rotation sequence/Grazing system……..

Current annual fertiliser regime/application rates……

……

……

Date of last fertiliser application to sample paddock……

Fertiliser history - past 5 years (if differs from above)……

……

……

Irrigation yes/no type……

Effluent application yes/no type, frequency etc..……

……

Artificial drainage yes/no type……

Broad scale chemical applications……

……

If you use a computer model such as the **OVERSEER®** Nutrient Budgets **Model,** please could you attach a copy of the inputs and output pages.