Soil Quality State of the Environment monitoring programme

Annual data report, 2016/17

John Drewry
Environmental Science Department

For more information, contact the Greater Wellington Regional Council:

Wellington
PO Box 11646

T 04 384 5708
F 04 385 6960
www.gw.govt.nz

Masterton
PO Box 41

T 06 378 2484
F 06 378 2146
www.gw.govt.nz

GW/ESCI-T-17/101

September 2017

www.gw.govt.nz
info@gw.govt.nz

Report prepared by:	J Drewry	Senior Scientist	John Drewry
Report reviewed by:	P Crisp	Team Leader	
Report approved for release by:	L Butcher	Manager, Environmental Science	Date: November 2017

The report may be cited as:

Drewry J. 2017. Soil Quality State of the Environment monitoring programme: Annual data report 2016/17. Greater Wellington Regional Council, Publication No GW/ESCI-T-17/101. Wellington.

Contents

1. Introduction

This report summarises the key results from the Soil Quality State of the Environment (SoE) monitoring programme for the period 1 July 2016 to 30 June 2017 inclusive. The Soil SoE programme incorporates annual monitoring of soil quality at various monitoring sites on soils across the region under different land uses.

A reduction in soil quality can result in reduced agricultural yields, and less resilient soil and land ecosystems. Changes in soil quality can also be associated with changes in environmental risks, including potential effects on waterways, animal health and greenhouse gas emission.

This report summarises the results of the soil monitoring undertaken at 23 sites which were predominantly mixed cropping farms and market gardens, but included several other land uses. It is not the intention to provide an in-depth discussion of results, conclusions or implications in this report, as it is a data report only.

2. Overview of SoE monitoring programme

Greater Wellington Regional Council (GWRC) became involved in a national soil quality programme known as the "500 Soils Project" in 2000 (Sparling & Schipper 2004). The intention of that project was to measure and assess soil quality from 500 sites throughout New Zealand. After completion of the project, GWRC implemented a soil quality monitoring programme to continue monitoring the quality of soils in the Wellington Region.

As part of the 500 Soils Project, a standard set of sampling methods, as well as physical, chemical and biological soil properties, were identified to assess soil quality, particularly for State of the Environment and regional council reporting (Land Monitoring Forum 2009). These sampling methods and soil quality indicators were adopted for use in GWRC's soil quality monitoring programme.

2.1 Monitoring objectives

The objectives of GWRC's soil quality monitoring programme are to:

- Provide information on the physical, chemical and biological properties of soils;
- Provide an early-warning system to identify the effects of primary land uses on long-term soil productivity and the environment;
- Track specific, identified issues relating to the effects of land use on long-term soil productivity;
- Assist in the detection of spatial and temporal changes in soil quality; and
- Provide information required to determine the effectiveness of regional policies and plans.

2.2 Monitoring network

GWRC's soil quality monitoring programme includes over 100 monitoring sites on soils across the region under different land uses. The frequency of sampling is dependent on the intensity of the land use; dairying, cropping and market garden sites are sampled every 3-4 years, drystock, horticulture and exotic forestry sites are sampled every 5-7 years, while indigenous vegetation sites are sampled every 10 years.

Twenty three sites were sampled during 1-8 May 2017 (Figure 2.1; Table 2.1). Sites sampled were predominantly mixed cropping (arable) and market garden land uses/farm systems. The sites were eight mixed cropping sites, seven market gardens, two dairy sites, and four drystock sites. Several sites where land use has changed since 2000 had been cropped or had market garden land use in the earlier samplings. There were 12 sites in the Ruamahanga catchment area (whaitua) region, and 11 in the Kapiti Coast whaitua area.

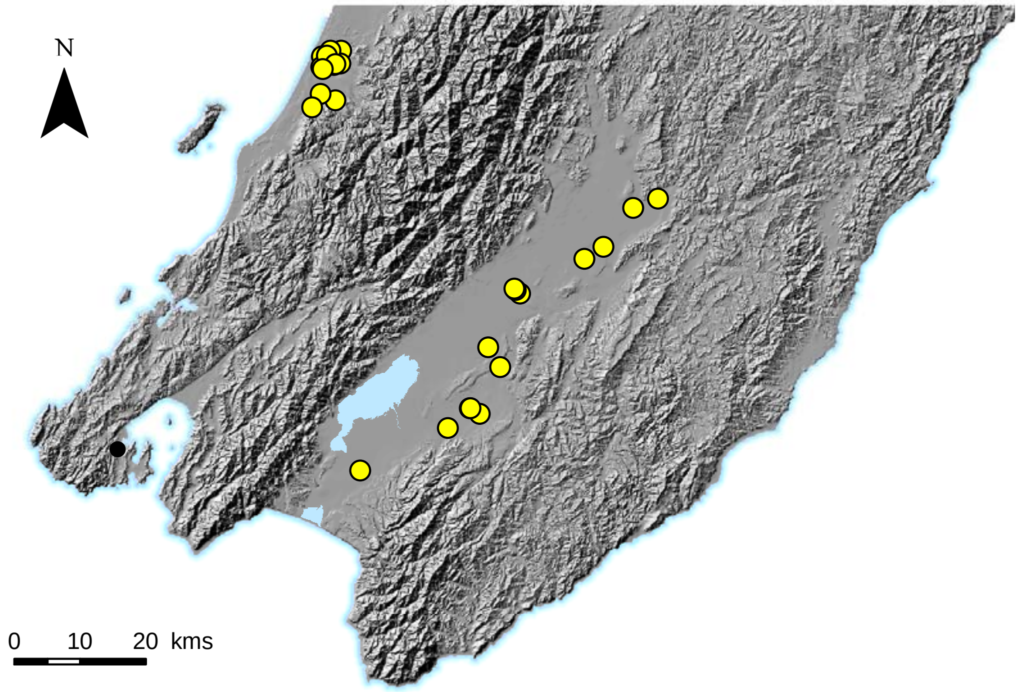

Figure 2.1: Greater Wellington's soil quality monitoring sites sampled in 2016/17

A range of soil orders were sampled. Details of the soil order, group, subgroup, soil type, land use and farm system are presented in Table 2.1. The soil classification system used is the New Zealand Soil Classification (Hewitt 2010). Soil classification was determined by Landcare Research during previous soil monitoring of the region. Further information and soil descriptions can be obtained from earlier reports such as Sparling (2005).

Soil orders that were sampled included Brown, Gley, Pallic and Recent soils. Brown Soils are characterised by brown colours due to iron oxide and are the most extensive soil order in New Zealand. Gley Soils are poorly or very poorly drained. Pallic Soils generally have high erosion potential and high subsoil density and Recent Soils have minimal soil profile development (McLaren & Cameron 1996; Hewitt 2010).

At each site, a 50 m transect was used to take soil cores. Soil cores 2.5 cm in diameter and 10 cm in depth were taken approximately every 2 m along the transect. The individual cores were bulked and mixed in preparation for chemical and biological analyses.

Three undisturbed (intact) soil samples were also obtained from each site. The intact soil cores were collected at 15, 30 and 45 m intervals along the transect by pressing steel liners (10 cm in diameter and 7.5 cm in depth) into the top 10 cm of soil, taking care to preserve the soil structure. From these intact cores a 3 cm subsample ring was used in the laboratory to determine the physical properties of the soil such as bulk density, porosity, macroporosity and selected water holding contents. Further details on field methods are presented in Land Monitoring Forum (2009).

Three soil samples were also obtained from each site for aggregate stability. The aggregate stability samples were collected at 15, 30 and 45 m intervals along the transect by using a spade to collect a block of the top 10 cm of soil, taking care to preserve the soil aggregates. Approximately 2 L volume of soil was collected for each aggregate stability sample.

Table 2.1: Soil order, subgroup, soil type, current land use and farm system for sites sampled

Site	Soil order	Soil subgroup	Soil type	Land use, farm system or vegetation when sampled in 2017
GW016	Gley	Typic Recent Gley	Ahikouka clay loam	Mixed cropping. Maize stubble. Autumn 2017 grass. Previous years radish for seed, grass, peas
GW017	Pallic	Argillic Perch-gley Pallic	Kokotau silt loam	Mixed cropping. Oats drilled 3 days prior to sampling. Sampled between drill rows to avoid fertiliser. Previous years grass, barley, wheat, peas, pasture
GW021	Gley	Typic Recent Gley	Ahikouka clay loam	Drystock. Pasture. Sheep grazing
GW022	Recent	Acidic-weathered Fluvial Recent	Greytown silt loam	Mixed cropping. Pasture with sheep grazing when sampled. Previously cropping maize, other crops grown are peas, barley, brassicas
GW027	Recent	Acidic-weathered Fluvial Recent	Manawatu very fine sandy loam	Drystock. Pasture. No stock grazing currently
GW031	Pallic	Mottled Immature Pallic	Martinborough loam	Drystock. Pasture and sheep
GW044	Brown	Mottled Orthic Brown	Rahui silt loam	Dairy. Currently fodder beet for dairy, crop not yet grazed. Previously pasture
GW071	Gley	Recent Gley	Ahikouka silt loam	Mixed cropping. Currently pasture and red clover. Recent years red clover, and barley for several years
GW075	Recent	Weathered Fluvial Recent	Greytown silt loam	Market garden. Currently fallow, weeds
GW079	Gley	Recent Gley	Ahikouka silt loam	Mixed cropping. Currently pasture which had been mown after sampling. Has recently moved away from intensive cropping. Previously grown beets, grass/clover, cereal
GW080	Recent	Weathered Fluvial Recent	Greytown silt loam	Mixed cropping. Currently pasture which had been mown after sampling. Has recently moved away from intensive cropping. Previously grown grass/clover, cereal
GW082	Gley	Typic Recent Gley	Otukura stony silt loam	Mixed cropping. Currently silver beet for seed. Previous years barley, rocket, vegetable and arable seeds
GW085	Gley	Recent Gley	Ahikouka silt loam	Dairy. Currently pasture
GW086	Gley	Recent Gley	Ahikouka silt loam	Mixed cropping. Current rotation is pasture and sheep grazing. Oats last year, previously grass seed, peas

Site	Soil order	Soil subgroup	Soil type	Land use, farm system or vegetation when sampled in 2017
GW087	Recent	Weathered Fluvial Recent	Manawatu silt loam	Drystock. Pasture and horses
GW090	Brown	Typic Orthic Brown	Te Horo silt loam	Market garden. Currently brassicas, cabbages, spinach. Sampled in recently planted area
GW092	Gley	Typic Orthic Gley	Kairanga silt loam	Market garden. Currently fallow, weeds. Previous years fallow, pumpkin and peppers
GW093	Recent	Weathered Fluvial Recent	Manawatu silt loam	Market garden. Currently fallow area, other parts of garden has beans, cabbage etc
GW094	Recent	Weathered Fluvial Recent	Manawatu silt loam	Market garden. Previously fallow, brassicas, kale, cauliflower, cabbage etc
GW107	Recent	Weathered Orthic Recent	Manawatu silt loam	Market garden. Kale, lettuce etc
GW108	Gley	Typic Orthic Gley	Kairanga clay loam	Market garden. Spring onions, beans etc
GW111	Brown	Typic Orthic Brown	Hautere clay loam	Mixed cropping. Currently pasture. Was maize a year ago, previously peas, maize
GW112	Pallic	Typic Immature Pallic	Shannon silt loam	Market garden. Lettuce

2.3 Monitoring variables

Soil properties are measured and used as indicators of soil quality. Soil quality indicators include bulk density, macroporosity, total carbon, total nitrogen, anaerobic mineralisable nitrogen, pH, Olsen P and heavy metal trace elements. These indicators can be grouped into four general areas of soil quality: physical condition, organic resources, fertility and trace elements, which together help provide an overall assessment of soil health. A summary of the indicators is provided in Table 2.2. The description of indicators monitored and why they are important is presented in Appendix 1. Details of analytical methods are provided in Appendix 2. Further details on laboratory methods are presented in Land Monitoring Forum (2009).

Table 2.2: Indicators used for soil quality assessment

Indicator	Soil quality information
Bulk density	Soil compaction and soil density
Macroporosity	Soil compaction of large pores and degree of aeration
Total carbon (C) content	Organic matter carbon content
Total nitrogen (N) content	Organic matter nitrogen content
Anaerobic mineralisable N	Organic nitrogen potentially available for plant uptake and activity of soil organisms.
Soil pH	Soil acidity
Olsen P	Plant-available phosphate
Total recoverable trace elements	Accumulation of trace elements

Olsen P measurements were undertaken by Landcare Research on a gravimetric (weight) basis and therefore avoided the influence of soil bulk density. In New Zealand several large commercial laboratories measure soil by volume and some fertiliser industry guidelines for Olsen P use the volumetric method. Further information and interpretation of Olsen P measurement methods are discussed in Drewry et al. (2013; 2015).

The Land Monitoring Forum specifies that macroporosity should be measured at a soil matric potential of -10 kPa. Ambiguity may arise with other terms (e.g. air-filled porosity). Ambiguity may also arise if macroporosity is measured at other soil matric potentials because different pore sizes would therefore be measured (Drewry et al. 2008; 2015).

An additional indicator for cropping farms and market gardens called aggregate stability was measured this year. Aggregates with low aggregate stability have low structural stability and are more prone to breakdown, dispersion and erosion by wind and water. Aggregate stability measurements were undertaken by Plant and Food Research.

2.4 Soil quality targets and guidelines

Soil quality indicators can be used to assess how land use and management practices influence soil for plant growth or for potential risks to the environment. To help improve interpretation of soil quality indicators, targets for indicators were developed and are now commonly used by regional councils (Hill & Sparling 2009). Target ranges for the assessment of soil quality (eg, very low, optimal, very high) for the predominant soil orders under different land uses are used (Hill & Sparling 2009). The interpretative ranges are presented in Appendix 3.

For this report, the suggested target range for selected indicators is the reporting ‘by exception’ as recommended by Hill and Sparling (2009). These guidelines are currently used by other regional councils in reporting soil quality monitoring, so are used in this report for consistency. Target ranges for soil orders, rather than land use, are available in Hill and Sparling (2009) for total carbon and bulk density. Some interpretive target ranges are still under development, particularly when examining environmental rather than production criteria (Hill & Sparling 2009). Some consideration to other guidelines or research information is also used in this report. Olsen P targets have been revised from those reported in Hill and Sparling (2009) with new target values reported in Taylor (2011a) and in Mackay et al. (2013). Further information is also available from Drewry et al. (2013; 2015).

2.5 Trace element targets, draft eco-soil guidelines and trigger values

Draft eco-soil guideline values (Eco-SGVs) have recently been developed to protect soil and terrestrial biota namely soil microbes, invertebrates, plants, wildlife and livestock (Cavanagh 2016). Eco-SGVs provide a useful means to assess potential environmental impact. Some soil guideline values already exist, but are for a limited number of contaminants and are based on inconsistent methodologies. The absence of national Eco-SGVs in the past has resulted in inconsistency and a lack of clarity around protection of ecological receptors. These issues have led to the development of these draft guideline values (Cavanagh 2016).

In the context of this report and monitoring programme, Eco-SGVs are intended to provide a benchmark for assessing soil quality over time in relation to regional council State of the Environment monitoring. The draft Eco-SGVs developed in a recent Envirolink Tools project are presented in this report, and in Appendix 3.

The trace element results have been compared to the soil targets presented in the New Zealand Water and Wastes Association (NZWWA 2003) ‘Guidelines for the Safe Application of Biosolids to Land in New Zealand’. While guidelines containing soil contaminant values have been written for a specific activity (eg, biosolids application), the values are generally transferable to other activities that share similar hazardous substances (MAF 2008). The biosolids guideline values for selected trace elements are presented in Appendix 3. The Health and Environmental Guidelines for Selected Timber Treatment Chemicals (MFE 1997), for example, can be used for assessing the concentrations of specific trace elements.

Cadmium results can also be compared against the trigger values in the Tiered Fertiliser Management System (TFMS) from the New Zealand Cadmium Management Strategy (MAF 2011). This strategy, developed in response to concerns about the accumulation of cadmium in soils from phosphate fertiliser usage, recommends different management actions at certain trigger values.

Cadmium trigger values from the TFMS are presented in Appendix 3. The numbering of the tiers was recently updated by Cavanagh (2012). Some caution is needed when interpreting values because the soil samples in this report were taken at a depth of 0-10 cm based on the methods in Hill and Sparling (2009), while the TFMS methodology is based on a depth of 0-7.5 cm for uncultivated land. Further information for soil quality indicators for these depths is available in Drewry et al. (2013).

3. Results

3.1 Soil results for the region

This section summarises the results of the soil quality monitoring across the region. Results are presented as mean values for the predominant land uses sampled this year.

Results are also summarised for comparison with the suggested ‘by exception’ target ranges reported in Hill and Sparling (2009) if available, or most recent targets in Taylor (2011a) and Mackay et al. (2013). Olsen P target ranges are reported in Taylor (2011a) and Mackay et al. (2013). Target values are presented in Appendix 3.

Across the region, for all the physical, chemical, trace element and aggregate stability soil quality indicators, three out of 23 sites sampled (13%) had all soil indicators within the soil and/or the land use target range described above. In contrast, for all the physical, chemical, trace element and aggregate stability indicators, 20 out of 23 sites sampled (87%) had one or more soil indicators that did not meet the soil and/or the land use target range described above. The number of sites sampled across the whole region that did not meet the target range is shown in more detail in Table 3.1. Further results are presented in the following sections for each whaitua region.

Table 3.1: Number of sites with indicators (including trace elements and aggregate stability) outside target range for the region

Number of Indicators and trace elements outside range	Number of sites	Percentage of sites in region that have indicators and trace elements outside target range
0	3	13
1	4	17
2	5	22
3	3	13
4	5	22
5	3	13

Physical and chemical soil quality indicator mean values for the predominant land uses sampled this year are presented in Table 3.2. Results for individual soil quality monitoring sites are presented later in the report. Mean soil pH was 6.2 on the mixed cropping land use sites and 6.4 on market garden sites sampled (Table 3.2). All sites had soil pH within the target range. Mean soil carbon was lower on the market garden and mixed cropping land use sites than the dairy and drystock sites (Table 3.2). There were nine sites across the region that did not meet the total carbon levels within the target range. Mean total nitrogen per land use was 0.20% to 0.29% for land uses sampled. One site did not meet the total nitrogen target range. The C:N ratio across all the sites ranged from 9.2 to 13.9. Mean soil anaerobic mineralisable nitrogen per land use ranged from 32 mg/kg to 75 mg/kg. Only two market garden sites did not meet the anaerobic mineralisable nitrogen target range.

Mean soil Olsen P was similar across mixed cropping and dairy/drystock sites (58 and 59 mg/kg, respectively) and 140 mg/kg for market garden sites. Olsen P was highly variable between sites ranging from 24 to 122 mg/kg for mixed cropping sites, 40 to 219 mg/kg for market garden sites, and 27 to 113 mg/kg across dairy/drystock sites. Fourteen of the 23 sites across the region did not meet (i.e., were less than or exceeded) the Olsen P target range recommended by Taylor (2011a) and Mackay et al. (2013). Note that these results are expressed on a gravimetric basis. Some caution should be applied if comparing with some guidelines or volumetric laboratory methods. See Drewry et al. (2013; 2015) for further details and explanation.

The highest Olsen P values recorded were from samples collected from some market garden sites. Vegetable production Olsen P targets vary depending on soil P retention properties, e.g. those reported by Clarke et al. (1986) using the former MAF commercial volumetric method. For average values of P retention, Clarke et al. (1986) recommended an Olsen P target value of 36-55 mg/L for legumes, 46-55 mg/L for brassicas, and 36-75 mg/L for spinach and silverbeet. There were six out of eight (75%) market gardens sampled in the region which exceeded those production target Olsen P values. Targets in Taylor (2011a) and Mackay et al (2013) however also account for environmental effects, rather than taking a production-only perspective. Production-only Olsen P targets for vegetable production tend to be greater than environmental targets. Of note is that Olsen P values for many market garden and other land use sites also exceed production targets, representing potential cost implications for farmers.

Mean soil bulk density for mixed cropping and market gardens was similar, (Table 3.2). Across the region, six sites had soil bulk density exceeding the upper target value of 1.4 Mg/m^3.

Mean soil macroporosity for market gardens was greater than for other land uses (Table 3.2). There was considerable variation in macroporosity values depending on phase of the farm system (e.g., recent cultivation), being 3.2% to 21.7% for mixed cropping, 9.6% to 20.1% for market gardens and 2.7% to 14.8% for the dairy/drystock sites sampled. There were eight sites with macroporosity values that are considered to be low, i.e. below 10% v/v (Drewry et al. 2008; Hill and Sparling 2009).

Seventeen of the 23 sites across the region did not meet the aggregate stability mean weight diameter (mwd) target recommended by Plant and Food Research. These sites included all the market gardens and most mixed cropping sites.

Table 3.2: Chemical and physical soil quality indicators for land use for the region. Means are presented.

Land use or farm system	Soil order	N	pH	Organic carbon (%)	Total N (%)	Anaerobic mineralisable-N (mg/kg)	Olsen P (mg/kg)	Bulk density (Mg/m^3)	Macroporosity(-10kPa % v/v)	Aggregate stability (m.w.d mm)
Mixed cropping	All	9	6.2	2.6	0.26	53	58	1.29	10.5	1.20
Market garden	All	8	6.4	2.2	0.20	32	140	1.27	15.9	0.50
Dairy + drystock	All	6	6.0	3.0	0.29	75	59	1.19	9.4	1.73

N is number of sites

3.2 Soil results for Ruamahanga whaitua

This section summarises the results of the soil quality monitoring across the Ruamahanga whaitua. Results are summarised for comparison with the suggested ‘by exception’ target ranges as described in the earlier sections.

Across the Ruamahanga whaitua, for all of the physical, chemical, trace element and aggregate stability soil quality indicators, two out of 12 sites sampled (17%) had all soil indicators within the soil and/or the land use target range described above. In contrast, 10 out of 12 sites sampled (83%) had soil indicators that did not meet the soil and/or the land use target range described above. The number of sites sampled in the whaitua that did not meet the target range is shown more detail in Table 3.3.

Table 3.3: Number of sites with indicators (including trace elements and aggregate stability) outside target range in Ruamahanga whaitua

Number of Indicators and trace elements outside range	Number of sites	Percentage of sites in region that have indicators and trace elements outside target range
0	2	17
1	2	17
2	4	33
3	1	8
4	2	17
5	1	8

Results for individual soil quality monitoring sites for soil chemical and physical properties for the Ruamahanga whaitua are presented in Table 3.4. All Ruamahanga whaitua sites had soil pH, total N, and anaerobic mineralisable nitrogen within the target range. Olsen P was variable ranging from 24-76 mg/kg over all sites in the whaitua. Six of the 12 sites did not meet the Olsen P target range recommended by Taylor (2011a) and Mackay et al. (2013). Note that these results are expressed on a gravimetric basis. Some caution should be applied if comparing with some guidelines or volumetric laboratory methods. See Drewry et al. (2013; 2015) for further details and explanation.

Three of the Ruamahanga whaitua sites did not meet the bulk density target range. There was one site with macroporosity values of 2.7% v/v, which is a level that is considered to be very low (Drewry et al. 2008; Hill and Sparling 2009). Across the whaitua, five sites sampled had macroporosity values below the recommended target range.

Results for individual soil quality monitoring sites for trace elements for the Ruamahanga whaitua are presented in Table 3.5. Trace element (total recoverable) concentrations in samples from soil monitoring sites in the whaitua were below the target range. All sites had cadmium concentrations below the MAF (2011) TFMS trigger value of 1.0 mg/kg. There were no sites that had a cadmium concentration value >0.6 to 1.0 mg/kg. Trace element values were below the draft eco-soil guideline values that have recently been developed to protect soil and terrestrial biota (Cavanagh 2016).

Nine of the 12 sites across the Ruamahanga whaitua did not meet the aggregate stability target (>1.5 mm) recommended by Plant and Food Research (Table 3.6). These sites were from cropping and several other land use sites. Mean aggregate stability, as measured by the mean of percentage of aggregates >1 mm, was 1.18% on cropping sites, and 1.68% on pastoral sites. Aggregate stability, as measured by the percentage of aggregates >1 mm, was low on one market garden site and on the cropping sites (Table 3.6).

Table 3.4: Results for individual soil quality monitoring sites in the Ruamahanga whaitua. Values highlighted in orange are outside the target or guideline range.

Site Name	Land use or farm system	Soil Order	pH	Total carbon (%)	Total N (%)	Anaerobic mineralisable -N (mg/kg)	Olsen P (mg/kg)	Bulk density (Mg/m^3)	Macro porosity (-10kPa % v/v)	Aggregate stability (mm)	Trace elements outside target range	Indicators and trace elements outside range
GW016	Mixed cropping	Gley	6.2	2.4	0.25	50	31	1.22	10.3	1.00	0	2
GW017	Mixed cropping	Pallic	6.4	3.4	0.33	75	59	1.10	15.7	1.78	0	1
GW021	Drystock	Gley	6.1	4.3	0.41	101	40	0.89	14.8	1.74	0	0
GW022	Mixed cropping	Recent	5.9	2.4	0.26	59	47	1.43	3.2	1.05	0	4
GW031	Drystock	Pallic	5.8	3.1	0.29	58	35	1.22	13.6	2.04	0	0
GW071	Mixed cropping	Gley	6.2	3.1	0.32	46	76	1.28	9.0	1.20	0	3
GW075	Market garden	Recent	5.7	2.0	0.19	39	44	1.31	17.0	0.80	0	2
GW079	Mixed cropping	Gley	7.0	1.8	0.18	34	62	1.44	5.4	0.77	0	5
GW080	Mixed cropping	Recent	6.7	1.6	0.17	37	28	1.44	6.7	0.99	0	4
GW082	Mixed cropping	Gley	5.6	3.8	0.36	76	74	1.15	21.7	1.48	0	2
GW085	Dairy	Gley	6.0	3.2	0.33	56	28	1.29	2.7	1.27	0	2
GW086	Mixed cropping	Gley	6.1	2.8	0.30	54	24	1.10	18.2	1.20	0	1
Target range												
Pallic and Recent soil								0.4-1.4				
Other soils				2.5->12				0.7-1.4				
Recent soil				2->12								
Pasture			5-6.6		0.25-0.70	>50			10-30	>1.5		
Pasture on sedimentary soils							20-40					
Cropping/horticulture			5-7.6		Excl	>20	20-40		10-30	>1.5		
Number of sites not meeting target			0/12	3/12	0/12	0/12	6/12	3/12	5/12	9/12	0/12	

Table 3.5: Trace element concentrations (total recoverable) in Ruamahanga whaitua. Values in colour are outside the guideline.

Site Name	Land use	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)
GW016	Mixed cropping	9.8	0.28	25	16.7	26	23	84
GW017	Mixed cropping	3.1	0.18	13.1	5.3	9.9	6.5	31
GW021	Drystock	3.5	0.19	24	13.1	19.1	17.6	78
GW022	Mixed cropping	5.3	0.21	21	13.6	17.2	18.8	68
GW031	Drystock	1.6	0.20	14.2	3.5	6.4	8.2	33
GW071	Mixed cropping	2.7	0.23	21	7.3	10	16.7	56
GW075	Market garden	4.1	0.09	21	13.1	13.4	16.1	61
GW079	Mixed cropping	8	0.24	26	18.3	23	23	80
GW080	Mixed cropping	6.6	0.12	26	17.1	22	23	79
GW082	Mixed cropping	4.8	0.17	16	2.6	13.8	7.3	26
GW085	Dairy	6.2	0.23	24	17.6	21	21	84
GW086	Mixed cropping	3.5	0.18	20	9.5	14.9	16.7	75
Target or guideline range		<20	<1	<600	<100	<300	<60	<300
Number of sites not meeting guideline		0	0	0	0	0	0	0
Other targets or guidelines								
TFMS Tier 0 cadmium target 0-0.6. Trigger value 0.6. TFMS Tier 1 cadmium target >0.6-1.0								
Number of sites >0.6-1.0, or greater								
Draft Eco-SGV agricultural land typical soil (Brown)		20	1.5	300	150	530		190
Draft Eco-SGV agricultural land sensitive soil (Recent)		20	1.5	300	130	530		130
TFMS Tier 0 cadmium target 0-0.6. Trigger value 0.6. TFMS Tier 1 cadmium target >0.6-1.0								
Note for Cu and Zn used the draft Eco-SGV for aged typical and sensitive reference soil								

* Tiered Fertiliser Management System (TFMS) as per the New Zealand Cadmium Management Strategy. Eco-SGV values are draft only.

Table 3.6: Aggregate stability for sites in Ruamahanga whaitua. Values in colour are outside the target or guideline.

Site	Land use	Average of Mean Weight Diameter of aggregates (mm)*	Average of percentage of aggregates >1 mm
GW016	Mixed cropping	1.00	31.5
GW017	Mixed cropping	1.78	64.3
GW021	Drystock	1.74	63.2
GW022	Mixed cropping	1.05	34.8
GW031	Drystock	2.04	73.5
GW071	Mixed cropping	1.20	41.9
GW075	Market garden	0.80	23.9
GW079	Mixed cropping	0.77	22.7
GW080	Mixed cropping	0.99	32.5
GW082	Mixed cropping	1.48	55.0
GW085	Dairy	1.27	45.2
GW086	Mixed cropping	1.20	43.0
	Target or guideline	MWD>1.5	>50%
	Number of sites not meeting target or guideline	9/12	8/12

* This is the indicator used to determine whether or not a site meets the target range for aggregate stability.

3.3 Soil results for Kapiti whaitua

This section summarises the results of the soil quality monitoring across the Kapiti whaitua. Results are summarised for comparison with the suggested 'by exception' target ranges as described in the earlier sections.

Across the Kapiti whaitua, there was one site of the 11 sampled that had all soil indicators within the soil and/or the land use target range described above. The number of sites sampled in the whaitua that did not meet the target range is shown in Table 3.7.

Table 3.7: Number of sites with indicators (including trace elements and aggregate stability) outside target range in Kapiti whaitua

Number of Indicators and trace elements outside range	Number of sites	Percentage of sites in region that have indicators and trace elements outside target range
0	1	9
1	2	18
2	1	9
3	2	18
4	3	28
5	2	18

Results for individual soil quality monitoring sites for soil chemical and physical properties for the Kapiti whaitua are presented in Table 3.8. All Kapiti whaitua sites had soil pH within the target range. Six Kapiti whaitua sites did not meet the soil carbon target range. Olsen P was variable, ranging from 27 to 219 mg/kg over all Kapiti sites. Nine of the 11 sites did not meet the Olsen P target range suggested by Taylor (2011a) and Mackay et al. (2013). Note that these results are expressed on a gravimetric basis. Some caution should be applied if comparing with some guidelines or volumetric laboratory methods. See Drewry et al. (2013; 2015) for further details and explanation.

Three Kapiti whaitua sites had bulk density that did not meet the soil target range. Across the whaitua, three sites sampled had macroporosity values below the recommended target range, indicating compacted soil.

Results for individual soil quality monitoring sites for trace elements for the whaitua are presented in Table 3.9. Trace element (total recoverable) concentrations in samples from soil monitoring sites in the whaitua were below the target range such as NZWWA (2003) guidelines. All sites had cadmium concentrations less than the MAF (2011) TFMS trigger value of 1.0 mg/kg. There were no sites that had a cadmium concentration value >0.6 to 1.0 mg/kg. Trace element values were below the draft Eco-soil guideline values that have recently been developed to protect soil and terrestrial biota (Cavanagh 2016).

Eight of the 11 sites across the Kapiti whaitua did not meet the aggregate stability target (MWD>1.5 mm) recommended by Plant and Food Research (Table 3.10). These were from market garden sites and one cropping site.

Aggregate stability, as measured by mean weight diameter of aggregates (mm), was lowest on market garden sites. Two market garden sites had very low values of mean weight diameter of aggregates (<0.5 mm; Table 3.9). Mean aggregate stability, as measured by the mean of percentage of aggregates >1 mm, was lowest on market garden sites. Four sites had very low values of percentage of aggregates >1 mm.

Table 3.8: Results for individual soil quality monitoring sites in the Kapiti whaitua. Values highlighted in orange are outside the target or guideline range.

Site Name	Land use or farm system	Soil Order	pH	Total carbon (%)	Total N (%)	Anaerobic mineralisable-N (mg/kg)	Olsen P (mg/kg)	Bulk density (Mg/m^3)	Macroporosity (-10kPa % v/v)	Aggregate stability (mm)	Trace elements outside target range	Indicators and trace elements outside range
GW027	Drystock	Recent	6.1	2.9	0.26	99	109	1.14	10.5	2.05	0	1
GW044	Dairy	Brown	5.8	2.6	0.26	70	27	1.17	11.3	1.66	0	0
GW087	Drystock	Recent	5.9	2.0	0.20	68	113	1.44	3.7	1.63	0	4
GW090	Market garden	Brown	6.5	2.5	0.26	37	40	1.15	14.8	0.66	0	1
GW092	Market garden	Gley	7.1	2.0	0.20	32	141	1.26	13.0	0.51	0	3
GW093	Market garden	Recent	6.6	1.9	0.18	31	166	1.30	17.1	0.47	0	3
GW094	Market garden	Recent	5.6	1.5	0.17	36	219	1.42	9.6	0.51	0	5
GW107	Market garden	Recent	6.0	1.4	0.15	19	191	1.34	20.1	0.29	0	4
GW108	Market garden	Gley	5.9	4.9	0.35	46	159	1.04	17.5	0.43	0	2
GW111	Mixed cropping	Brown	6.2	2.2	0.21	46	122	1.43	4.7	1.36	0	5
GW112	Market garden	Pallic	7.5	1.3	0.14	14	164	1.36	18.2	0.30	0	4
Target range												
Pallic and Recent soil								0.4-1.4				
Other soils				2.5->12				0.7-1.4				
Recent soil				2->12								
Pasture			5-6.6		0.25-0.70	>50			10-30	>1.5		
Pasture on sedimentary soils							20-40					
Cropping/horticulture			5-7.6		Excl	>20	20-40		10-30	>1.5		
Number of sites not meeting target			0/11	6/11	1/11	2/11	9/11	3/11	3/11	8/11	0/11	

Table 3.9: Trace element concentrations (total recoverable) in Kapiti whaitua. Values in colour are outside the guideline.

Site Name	Land use	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)
GW027	Drystock	8.3	0.33	25	33	24	21	93
GW044	Dairy	5.3	0.13	19.6	10.9	13.9	15.5	65
GW087	Drystock	6.9	0.28	20	56	21	17.6	85
GW090	Market garden	4	0.23	26	14.1	15.7	17	75
GW092	Market garden	9.9	0.34	26	24	55	21	112
GW093	Market garden	9.7	0.38	32	57	38	24	106
GW094	Market garden	8.5	0.38	24	88	30	19.3	95
GW107	Market garden	11.3	0.46	19.9	68	31	16.6	102
GW108	Market garden	3.5	0.28	23	31	24	14.3	74
GW111	Mixed cropping	3.3	0.30	22	17.6	14.1	13.5	70
GW112	Market garden	3.4	0.14	16.9	21	10.4	9.8	52
Target or guideline range		<20	<1	<600	<100	<300	<60	<300
Number of sites not meeting guideline		0	0	0	0	0	0	0
Other targets or guidelines								
TFMS Tier 0 cadmium target 0-0.6. Trigger value 0.6. TFMS Tier 1 cadmium target >0.6-1.0								
Number of sites >0.6-1.0, or greater								
Draft Eco-SGV agricultural land typical soil (Brown)		20	1.5	300	150	530		190
Draft Eco-SGV agricultural land sensitive soil (Recent)		20	1.5	300	130	530		130
TFMS Tier 0 cadmium target 0-0.6. Trigger value 0.6. TFMS Tier 1 cadmium target >0.6-1.0								
Note for Cu and Zn used the draft Eco-SGV for aged typical and sensitive reference soil								

* Tiered Fertiliser Management System (TFMS) as per the New Zealand Cadmium Management Strategy. Eco-SGV values are draft only.

Table 3.10: Aggregate stability for sites in Kapiti whaitua. Values in colour are outside the target or guideline.

Site	Land use	Average of Mean Weight Diameter of aggregates (mm)	Average of percentage of aggregates >1 mm
GW027	Drystock	2.05	77.2
GW044	Dairy	1.66	63.8
GW087	Drystock	1.63	59.6
GW090	Market garden	0.66	17.1
GW092	Market garden	0.51	10.9
GW093	Market garden	0.47	8.9
GW094	Market garden	0.51	10.7
GW107	Market garden	0.29	1.5
GW108	Market garden	0.43	7.4
GW111	Mixed cropping	1.36	46.2
GW112	Market garden	0.30	1.8
	Target or guideline	MWD>1.5	>50%
	Number of sites not meeting target	8/11	8/11

* This is the indicator used to determine whether or not a site meets the target range for aggregate stability.

Acknowledgements

Thanks to the farmers and landowners who provided information and access to their land for sampling and to Richard Parkes and Jamie Peryer for assistance with sampling.

References

Alloway, BJ. 2008. Copper and zinc in soils: too little or too much? In: (Ed N. Kim) New Zealand Trace Elements Group conference. Hamilton. 10 p.

Cavanagh J. 2012. *Working towards New Zealand risk-based soil guideline values for the management of cadmium accumulation on productive land*. Ministry for Primary Industries, MPI Technical Paper No. 2012/06, Wellington.

Cavanagh J. 2016. *User Guide: Background soil concentrations and soil guideline values for the protection of ecological receptors (Eco-SGVs) – Consultation draft.* Envirolink Tools Grant: C09X1402. Prepared for Regional Waste and Contaminated Land Forum, Land Monitoring Forum and Land Managers Group. Landcare Research.

Clarke CJ, Smith GS, Prasad M and Cornforth IS. 1986. Fertiliser recommendations for horticultural crops. Ministry of Agriculture and Fisheries, Wellington.

Curran-Cournane F and Taylor A. 2012. *Concentrations of selected trace elements for various land uses and soil orders within rural Auckland.* Technical Report 2012/021. Auckland Council.

Drewry JJ, Paton RJ and Monaghan RM. 2004. *Soil compaction and recovery cycle on a Southland dairy farm: Implications for soil monitoring.* Australian Journal of Soil Research, 42: 851-856.

Drewry JJ, Cameron KC and Buchan GD. 2008. *Pasture yields and soil physical property responses to soil compaction from treading and grazing: A review.* Australian Journal of Soil Research, 46: 237-256.

Drewry J, Taylor M, Curran-Cournane F, Gray C and McDowell R. 2013. *Olsen P methods and soil quality monitoring: are we comparing 'apples with apples'?* Accurate and efficient use of nutrients on farms. (Eds LD Currie and CL Christensen). Occasional Report No. 26. Fertilizer and Lime Research Centre, Fertilizer and Lime Research Centre, Massey University.

Drewry, J, Curran-Cournane, F, Taylor, M, and Lynch, B. 2015. *Soil quality monitoring across land uses in four regions: implications for reducing nutrient losses and for national reporting*. In: Moving farm systems to improved nutrient attenuation. (Eds LD Currie and LL Burkitt). Occasional Report No. 28. Fertilizer and Lime Research Centre, Massey University.

Hewitt AE. 2010. *New Zealand soil classification.* Landcare Research.

Hill RB and Sparling GP 2009. *Soil quality monitoring.* Land and soil monitoring: A guide for SoE and regional council reporting. Land Monitoring Forum, New Zealand, pp. 27-86.

Kemper WD and Rosenau RC 1986. *Aggregate stability and size distribution*. Methods of soil analysis Part 1. Physical and mineralogical methods, 2nd edition, Soil Science Society of America, Madison, WI, pp. 425-442.

Kim ND and Taylor MD. 2009. *Trace element monitoring.* Land and soil monitoring: A guide for SoE and regional council reporting. Land Monitoring Forum, New Zealand, pp. 117-165.

Land Monitoring Forum. 2009. *Land and soil monitoring: A guide for SoE and regional council reporting.* Land Monitoring Forum, New Zealand.

MAF. 2008. *Cadmium in New Zealand Report One: Cadmium in New Zealand agriculture*. Report of the Cadmium Working Group. Ministry of Agriculture and Forestry, Information Paper, Wellington.

MAF. 2011. *Cadmium and New Zealand agriculture and horticulture: a strategy for long term risk management*. A report prepared by the Cadmium Working Group for the Chief Executives Environmental Forum. Ministry of Agriculture and Forestry, MAF Technical Paper No. 2011/02, Wellington.

McDowell RW, Biggs BJF, Sharpley AN and Nguyen L. 2004. *Connecting phosphorus loss from agricultural landscapes to surface water quality.* Chemistry and Ecology, 20: 1-40.

Mackay A, Dominati E, and Taylor MD. 2013. *Soil quality indicators: the next generation. Report prepared for Land Monitoring Forum of Regional Councils*. AgResearch.

McLaren RG and Cameron KC. 1996. *Soil science: Sustainable production and environmental protection.* Oxford University Press, Auckland.

MfE. 1997. *Health and environmental guidelines for selected timber treatment chemicals.* Ministry for the Environment, Wellington.

Nicholls A, van der Weerden T, Morton J, Metherell A and Sneath G. 2009. *Managing soil fertility on cropping farms.* New Zealand Fertiliser Manufacturers' Research Association.

NZWWA. 2003. *Guidelines for the safe application of biosolids to land in New Zealand.* New Zealand Water and Wastes Association, Wellington.

Roberts AHC and Morton JD. 2009. *Fertiliser use on New Zealand dairy farms*. New Zealand Fertiliser Manufacturers' Research, Auckland.

Sparling G and 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 G. 2005. *Implementing soil quality indicators for land: Wellington region 2004–2005.* Landcare Research Contract Report LC0405/070 prepared for Greater Wellington Regional Council.

Taylor MD. 2011a. *Towards developing targets for soil quality indicators in New Zealand: Findings of a review of soil quality indicators workshop*. 6th May 2011. Unpublished report, Land Monitoring Forum.

Taylor MD. 2011b. *Soil Quality and Trace Element Monitoring in the Waikato Region 2009*. Waikato Regional Council Technical Report 2011/13, Hamilton.

Vogeler I, Cichota R, Sivakumaran S, Deurer M and McIvor I. 2006. *Soil assessment of apple orchards under conventional and organic management.* Australian Journal of Soil Research, 44: 745-752.

Appendix 1: Soil quality indicators

Details of the soil indicators used are presented in Table A1.

Soil physical properties

The physical condition of the soil can affect transmission of water and air through soil and can subsequently affect plant yield. Soil physical conditions can also have implications on soil hydrology such as runoff and leaching and also the production of some greenhouse gases. Bulk density and macroporosity are indicators of soil physical condition, and therefore indicators of soil compaction. Bulk density is the mass of soil per unit volume (McLaren & Cameron 1996). Macroporosity is an indicator of the volume of large pores in the soil, commonly responsible for soil drainage and aeration. Macroporosity describes the volume percentage of pores >30 micron diameter (McLaren & Cameron 1996; Drewry et al. 2004; 2008). Macropores are primarily responsible for adequate soil aeration and rapid drainage of water and solutes (McLaren & Cameron 1996). Note that macroporosity has also been defined with different pore diameters in the literature. For the purposes of this report macroporosity is measured at -10 kPa matric potential.

Macroporosity has been shown to be a good indicator of soil physical condition. It is commonly a more responsive indicator of soil compaction than bulk density. Macroporosity values of less than 10–12% have often used to indicate limiting conditions for plant health and soil aeration (Drewry et al. 2008). Optimum soil macroporosity, for example, for maximum pasture and crop yield ranges from 6–17% v/v (Drewry et al. 2008). Soil compaction is commonly caused by either animal treading or the impact of machinery and tyres in wet soil conditions on horticulture orchards and cultivated land (Vogeler et al. 2006; Drewry et al. 2008). Soil compaction can also occur as a result of some forest harvesting management practices. Factors such as the loss of organic matter may also contribute to reduced soil physical quality.

Soil chemical properties

Soil organic matter helps retain moisture, nutrients and good soil structure for water and air movement. Soil carbon is used as an indicator of the soil organic matter content. Soil organic matter levels are particularly susceptible when land is used for market gardening and cropping. Intensive cultivation can lead to a reduction in soil organic matter through increasing the rate of organic matter decomposition, reducing inputs of organic residues to the soil and increasing aeration oxidation of the soil (McLaren & Cameron 1996).

Nitrogen (N) is an essential nutrient for plants and animals. Most nitrogen in soil is found in organic matter. Total nitrogen is used as an indicator. In general, high total nitrogen indicates the soil is in good biological condition. Very high total nitrogen contents increase the risk that nitrogen supply may be in excess of plant demand and lead to leaching of nitrate to groundwater and waterways.

Not all of the nitrogen in organic matter can be used by plants; soil organisms change the nitrogen to forms plants can use. Mineralisable nitrogen gives a measure of how much organic nitrogen is potentially available for plant uptake, and the activity of soil organisms (Hill & Sparling 2009). While mineralisable nitrogen is not a direct measure of soil biology, it has been found to correlate reasonably well with microbial biomass carbon, so mineralisable nitrogen can act as a surrogate measure for microbial biomass.

Soil pH is a measure of the degree of acidity or alkalinity of the soil (McLaren & Cameron 1996). Most plants and soil organisms have an optimum soil pH range for optimum growth. Soil pH can affect many chemical reactions in the soil such as availability and retention of nutrients. Commonly, lime is added to many New Zealand to change pH to the optimum range for plant growth.

Many New Zealand soils are inherently deficient in phosphorus, sulphur, to a lesser extent potassium and in some cases, trace elements (Roberts & Morton 2009). Inputs of fertiliser or other soil amendments (eg, effluent) are used to improve soil fertility. Olsen P is an indicator of the plant available fraction of phosphorus in the soil. Olsen P is a widely used soil test indicator in New Zealand and has been extensively used for calibration of pasture and plant yield responses (Roberts & Morton 2009) and crop responses (Nicolls et al. 2009). While soil Olsen P is well-recognised indicator of soil fertility, it is increasingly being used as a soil quality indicator of risk to waterways (McDowell et al. 2004). Phosphorus is commonly strongly bound to soils. Soil erosion causing sediment to reach waterways often carries sediment bound phosphorus, which may result in contamination of water and enhanced algal growth.

Soil trace elements

Trace elements such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn) can accumulate in soils as a result of common agricultural and horticultural land use activities such as the use of pesticides and the application of some types of effluent and phosphate fertilisers. While trace elements occur naturally, and the natural concentrations of most trace elements can vary greatly depending on geologic parent material, trace elements can become toxic at higher concentrations (Kim & Taylor 2009). Human activities associated with agriculture and other land uses can influence trace metals in soil (Curran-Cournane & Taylor 2012; Taylor 2011b).

Table A1: Indicators used for soil quality assessment (adapted from Hill & Sparling 2009)

Soil property	Indicator	Soil quality information	Why is this indicator important?
Physical condition	Bulk density	Soil compaction	Bulk density is a measure of soil density. A high bulk density indicates a compacted or dense soil. Movement of water and air through soil pores is reduced in compacted soils. High soil bulk density can restrict root growth and adversely affect plant growth. There is also potential for increased run-off and nutrient loss to surface waters in compacted soils.
	Macroporosity	Soil compaction of large pores and degree of aeration	Macropores are important for soil air movement and drainage. Large soil pores are the most susceptible to collapse when soil is compacted. Low macroporosity adversely affects plant growth due to poor root environment, restricted air movement and N-fixation by clover roots. It also infers poor drainage and infiltration.
Organic resources	Total carbon (C) content	Organic matter carbon content	Used as an estimate of the amount of organic matter. Organic matter helps soils retain moisture and nutrients, and gives good soil structure for water movement and root growth. Used to address the issue of organic matter depletion and carbon loss from the soil.
	Total nitrogen (N) content	Organic matter nitrogen content	Most nitrogen in soil is present within the organic matter fraction, and total nitrogen gives a measure of those reserves. It also provides an indication for the potential of nitrogen to leach into underlying groundwater.
	Anaerobic mineralisable N	Organic nitrogen potentially available for plant uptake and activity of soil organisms.	Not all nitrogen can be used by plants; soil organisms change nitrogen to forms that plants can use. Mineralisable N gives a measure of how much organic nitrogen is available to plants, and the potential for nitrogen leaching at times of low plant demand. Mineralisable nitrogen is also used as a surrogate measure of the microbial biomass.
Acidity	Soil pH	Soil acidity	Most plants have an optimal pH range for growth. The pH of a soil influences the availability of many nutrients to plants and the solubility of some trace elements. Soil pH is influenced by the application of lime and some fertilisers.
Fertility	Olsen P	Plant-available phosphate	Phosphorus (P) is an essential nutrient for plants and animals. Olsen P is a measure of the amount of phosphorus that is available to plants. Levels of P greater than agronomic requirements can increase P losses to waterways, and therefore contribute to eutrophication (nutrient enrichment).
Trace elements	Concentrations of total recoverable trace elements	Accumulation of trace elements	Some trace elements are essential micro-nutrients for plants and animals. Both essential and non-essential trace elements can become toxic at high concentrations. Trace elements can accumulate in the soil from various common agricultural and horticultural land use practices.

Appendix 2: Analytical methods

Analyses of the soil chemistry and soil physics indicators were completed at the Landcare Research laboratory (Table A2). Trace element analyses were undertaken at Hill Laboratories in Hamilton. Where necessary, samples were stored at 4°C until analysis.

Note that macroporosity was determined at the Landcare Research soil physics laboratory in Hamilton. The Land Monitoring Forum specifies that macroporosity should be measured at a matric potential of -10 kPa. Macroporosity is the percentage of pores > 30 microns in diameter, when measured at -10 kPa. Ambiguity may arise with other terms (e.g. air-filled porosity) or macroporosity measured at other matric potentials (Drewry et al. 2008; 2015).

Note that Olsen P measurements undertaken at Landcare Research were undertaken on a gravimetric (weight) basis and therefore avoid the influence of soil bulk density. In New Zealand several large commercial laboratories measure soil received in the laboratory by volume prior to Olsen P chemical extraction. The fertiliser industry guidelines for Olsen P are using the volumetric method. Further information and explanation is available from Drewry et al. (2013; 2015).

Table A2: Analytical methods

Indicator	Method
Bulk density	Measured on a sub-sampled core dried at 105°C.
Macroporosity	Determined by drainage on pressure plates at -10kPa.
Total C content	Dry combustion method. Using air-dried, finely ground soils using a Leco 2000 CNS analyser.
Total N content	Dry combustion method. Using air-dried, finely ground soils using a Leco 2000 CNS analyser.
Mineralisable N	Waterlogged incubation method. Increase in NH_4^+ concentration was measured after incubation for 7 days at 40°C and extraction in 2M KCl.
Soil pH	Measured in water using glass electrodes and a 2.5:1 water-to-soil ratio.
Olsen P	Bicarbonate extraction method. Extracting <2mm air dried soils for 30 minutes with 0.5M $NaHCO_3$ at pH 8.5 and measuring the PO_4^{3-} concentration by the molybdenum blue method.
Trace elements	Total recoverable digestion. Nitric/hydrochloric acid digestion, USEPA 200.2.

Aggregate stability samples were analysed at Plant and Food Research, at Lincoln. Aggregates 2–4 mm diameter were separated by dry sieving and then air-dried at 25°C for aggregate stability determination using a wet-sieving method (Kemper & Rosenau 1986). The air-dried 2−4 mm aggregates (50 g) were sieved underwater for 20 min on a nest of sieves (2.0, 1.0 and 0.5 mm diameter). The soil remaining on each sieve was weighed after oven drying at 105°C. The aggregate stability was expressed as a mean weight diameter (MWD).

Appendix 3: Soil quality targets

Soil quality indicator target ranges from Hill and Sparling (2009) are presented below. Soil quality indicator values in bold are the suggested 'by exception' target ranges from Hill and Sparling (2009). Guideline values for trace element concentrations in soil are adapted from NZWWA (2003).

Olsen P target ranges and the AMN upper target value from Hill and Sparling (2009) are no longer used. Updated targets for Olsen P and AMN from Taylor (2011a) and Mackay et al. (2013) are now used and presented below.

Bulk density target ranges (t/m^3 or Mg/m^3)

	Very loose	Loose	Adequate	Compact	Very compact	
Semi-arid, Pallic and Recent soils	0.3	0.4	0.9	1.25	1.4	1.6
Allophanic soils		0.3	0.6	0.9	1.3	
Organic soils		0.2	0.4	0.6	1.0	
All other soils	0.3	0.7	0.8	1.2	1.4	1.6

Macroporosity target ranges (% v/v at -10 kPa)

	Very low	Low	Adequate	High	
Pastures, cropping and horticulture	0	6	10	30	40
Forestry	0	8	10	30	40

Macroporosity updated guideline of 10-30% as adopted by Land Monitoring Forum

Total carbon target ranges (% w/w)

	Very depleted	Depleted	Normal	Ample	
Allophanic	0.5	3	4	9	12
Semi-arid, Pallic and Recent	0	2	3	5	12
Organic	exclusion				
All other Soil Orders	0.5	2.5	3.5	7	12

Total nitrogen target ranges (% w/w)

	Very depleted	Depleted	Normal	Ample	High	
Pasture	0	0.25	0.35	0.65	0.70	1.0
Forestry	0	0.10	0.20	0.60	0.70	
Cropping and horticulture	exclusion					

Mineralisable nitrogen target ranges (mg/kg)

	Very low	Low	Adequate	Ample	High	Excessive	
Pasture	25	50	100	200	200	250	300
Forestry	5	20	40	120	150	175	200
Cropping and horticulture	5	20	100	150	150	200	225

Note: Previous upper limits for AMN reported in Hill and Sparling (2009) are no longer used, as recommended by Taylor (2011a) and Mackay et al. (2013), and adopted by the Land Monitoring Forum.

Soil pH target ranges

	Very acid	Slightly acid	Optimal	Sub-optimal	Very alkaline	
Pastures on all soils except Organic	4	5	5.5	6.3	6.6	8.5
Pastures on Organic soils	4	4.5	5	6	7.0	
Cropping and horticulture on all soils except Organic	4	5	5.5	7.2	7.6	8.5
Cropping and horticulture on Organic soils	4	4.5	5	7	7.6	
Forestry on all soils except Organic		3.5	4	7	7.6	
Forestry on Organic soils	exclusion					

Olsen P target ranges (units not reported) from Taylor (2011a) and Mackay et al. (2013)

Land use	Soil Type	Suggested Olsen P targets
Pasture, Horticulture and cropping	Volcanic	20-50
Pasture, Horticulture and cropping	Sedimentary and Organic soils	20-40
Pasture, Horticulture and cropping	Raw sands and Podzols with low AEC	5
Pasture, Horticulture and cropping	Raw sands and Podzols with medium and above AEC	15-25
Pasture, Horticulture and cropping	Other soils	20-45
Pasture, Horticulture and cropping	Hill country	15-20
Forestry	All soils	5-30

Draft eco-soil guideline values for trace element concentrations in soil, from Cavanagh (2016). Values presented are for agricultural land use only.

Note that other values may apply for other land uses, soils and circumstances. Refer to Cavanagh (2016) for details.

Trace element	Draft eco-soil guideline value (mg/kg)	Notes
Arsenic (As)	20	
Cadmium (Cd)	1.5	
Chromium (Cr)	300	
Copper (Cu)	150	Eco-SGV agricultural land typical soil (Brown)
Copper (Cu)	130	Eco-SGV agricultural land sensitive soil (Recent)
Lead (Pb)	530	
Nickel (Ni)	Not determined	
Zinc (Zn)	190	Eco-SGV agricultural land typical soil (Brown)
Zinc (Zn)	130	Eco-SGV agricultural land sensitive soil (Recent)

Guideline values for trace element concentrations in soil, adapted from NZWWA (2003)

Trace element	Soil limit (mg/kg)
Arsenic (As)	20
Cadmium (Cd)	1
Chromium (Cr)	600
Copper (Cu)	100
Lead (Pb)	300
Nickel (Ni)	60
Zinc (Zn)	300

A suggested value for copper deficiency (≤ 5 mg/kg; Alloway 2008) and zinc deficiency (≤ 10 mg/kg; Alloway 2008) may be of interest depending on circumstances and type of farm production.

Cadmium tiers, concentrations and trigger values in the Tiered Fertiliser Management System (TFMS), (Cavanagh 2012)

Tier	Cadmium concentration (mg/kg)	Trigger value (mg/kg)
0	0-0.6	0.6
1	>0.6-1.0	1.0
2	>1.0-1.4	1.4
3	>1.4-1.8	1.8
4	>1.8	NA

Aggregate stability

Guidelines were obtained from Plant and Food Research. In this report aggregate stability values are given in millimetres mean weight diameter (MWD), which range between 0.25 and 3.0 mm MWD, and % >1 mm which is an indication of how stable the soil is. Soils below 1.5 mm MWD or 50% stability are at greater risk of producing less than the regional average yield.