Soil quality State of the Environment monitoring programme

Annual data report, 2013/14

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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 2013 to 30 June 2014 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 including nine cropping farms, nine market gardens and five other land use sites. 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.

Soil quality data are evaluated periodically for State of the Environment reporting (eg, Sorensen 2012).

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 28 April to 5 May 2014 (Figure 2.1; Table 2.1). Sites sampled in the 2013/14 year comprised predominantly cropping and market gardens sites with a variety of vegetable crops and several sites that are currently pasture. There were 12 sites in the Ruamahanga catchment area (whaitua) region and 11 in the Kapiti Coast whaitua area.

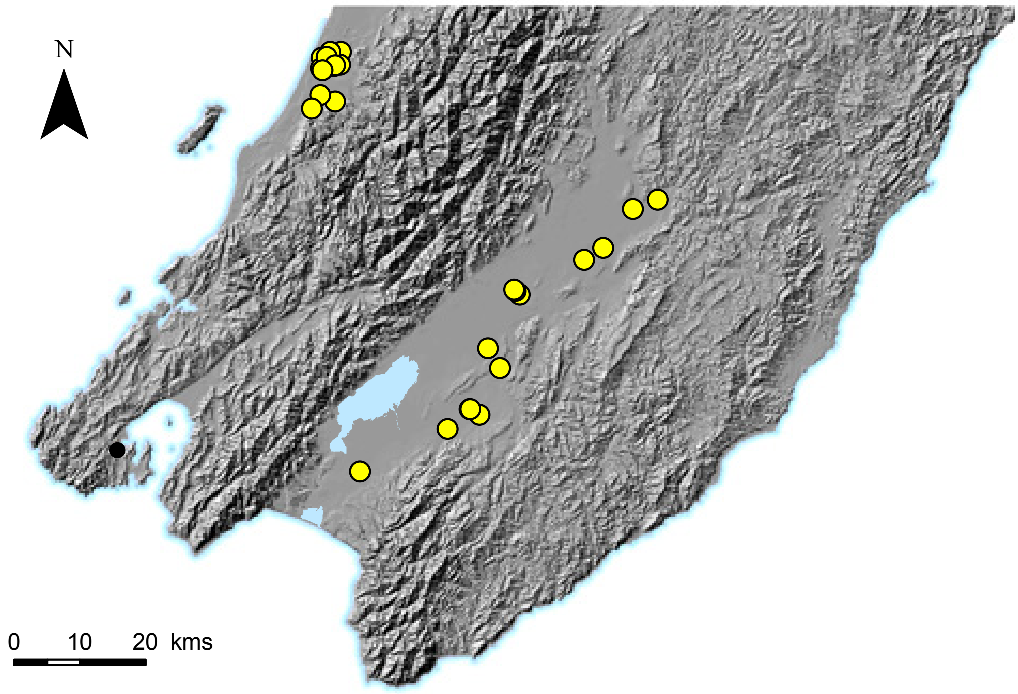

Figure 2.1: Greater Wellington's soil quality monitoring sites sampled in 2013/14

A range of soil orders were sampled. Details of the soil order, group, subgroup, soil series and land use 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 50m transect was used to take soil cores. Soil cores 2.5cm in diameter and 10cm in depth were taken approximately every 2m along the transect. The individual cores were bulked and mixed in preparation for chemical and biological analyses.

Table 2.1: Soil order, subgroup, soil series and current land use for sites sampled

Site	Soil order	Soil subgroup	Soil series	Land use
GW016	Gley	Typic Recent Gley	Ahikouka clay loam	Pasture for silage last 3 years. Drystock. Market garden prior to about 2003
GW017	Pallic	Argillic Perch-gley Pallic	Kokotau silt loam	Cropping. Currently pasture, recent years grass, barley, wheat, peas
GW021	Gley	Typic Recent Gley	Ahikouka clay loam	Pasture. Sheep and beef farming
GW022	Recent	Acidic-weathered Fluvial Recent	Greytown silt loam	Cropping. Maize
GW027	Recent	Acidic-weathered Fluvial Recent	Manawatu very fine sandy loam	Pasture. Recent years market garden
GW031	Pallic	Mottled Immature Pallic	Martinborough loam	Cropping. Currently pasture and sheep
GW044	Brown	Mottled Orthic Brown	Rahui silt loam	Pasture. Dairy. Farmer indicated has been dairy for many years
GW071	Gley	Recent Gley	Ahikouka silt loam	Cropping. Currently pasture and sheep. Recent years peas, barley, wheat
GW075	Recent	Weathered Fluvial Recent	Greytown silt loam	Market Garden. Currently ex courgettes
GW079	Gley	Recent Gley	Ahikouka silt loam	Cropping. Currently cereal
GW080	Recent	Weathered Fluvial Recent	Greytown silt loam	Cropping. Currently cereal
GW082	Gley	Typic Recent Gley	Otukura stony silt loam	Cropping. Barley and rocket. Newly sown crop. Recent years vegetable and arable seeds
GW085	Gley	Recent Gley	Ahikouka silt loam	Cropping. Currently newly ploughed and sown pasture
GW086	Gley	Recent Gley	Ahikouka silt loam	Cropping. Currently grass seed. Previously oats and maize
GW087	Recent	Weathered Fluvial Recent	Manawatu silt loam	Pasture
GW090	Brown	Typic Orthic Brown	Te Horo silt loam	Market Garden. Currently silverbeet. Recent years brassicas, leeks, beetroot, lettuce, green crop
GW092	Gley	Typic Orthic Gley	Kairanga silt loam	Market Garden. Fallow/weeds last 2 years. Recent years pumpkin and peppers
GW093	Recent	Weathered Fluvial Recent	Manawatu silt loam	Market Garden. Currently beans
GW094	Recent	Weathered Fluvial Recent	Manawatu silt loam	Market Garden. Eggplant. Other crops brassicas, courgettes etc
GW107	Recent	Weathered Orthic Recent	Manawatu silt loam	Market Garden. Coriander and cucumber
GW108	Gley	Typic Orthic Gley	Kairanga clay loam	Market Garden. Cabbages and broccoli
GW111	Brown	Typic Orthic Brown	Hautere clay loam	Market Garden. Peas, ex maize stubble
GW112	Pallic	Typic Immature Pallic	Shannon silt loam	Market Garden. Beetroot

Three undisturbed (intact) soil samples were also obtained from each site. The intact soil cores were collected at 15, 30 and 45m intervals along the transect by pressing steel liners (10cm in diameter and 7.5cm in depth) into the top 10cm of soil, taking care to preserve the soil structure. From these intact cores a 3cm 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 45m intervals along the transect by using a spade to collect a block of the top 10cm of soil, taking care to preserve the soil aggregates. Approximately 2L volume of soil was collected for each aggregate stability sample.

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 (adapted from Hill & Sparling 2009)

Indicator	Soil quality information
Bulk density	Soil compaction
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 avoid 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).

An additional indicator called aggregate stability was measured this year as most sites were cropping and market garden sites. Aggregates with low aggregate stability have low structural stability and are more prone to breakdown, dispersion and erosion by wind and water.

3. Results

3.1 Soil quality targets

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 from Hill and Sparling (2009) 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). Further information is also available from Drewry et al. (2013).

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 0-10cm based on the methods in Hill and Sparling (2009), while the TFMS methodology is based on a depth of 0-7.5cm for uncultivated land. Further information for soil quality indicators for these depths is available in Drewry et al. (2013).

3.2 Soil results overview

This section summarises the results of the soil quality monitoring. Results are presented as means and summarised for comparison with the suggested 'by exception' target ranges reported in Hill and Sparling (2009) if available. Olsen P target ranges reported in Taylor (2011a) are used. Aggregate stability is not a regular indicator in the 'by exception' target ranges, so the aggregate stability results are included separately.

Across the region, for all the physical, chemical and trace element soil quality indicators, two out of 23 sites sampled (9%) had all soil indicators within the soil and/or the land use target range suggested in Hill and Sparling (2009) and Taylor (2011a). The number of sites sampled across the region that did not meet the target range is as follows:

- One indicator - nine sites sampled (39%);
- Two indicators - six sites (26%);
- Three indicators - two sites (9%);
- Four indicators - three sites (13%); and
- Five indicators - one site (4%).

In the Ruamahanga whaitua area, for all the physical, chemical and trace element soil quality indicators, two out of 12 sites sampled (16%) had all soil indicators within the soil and/or the land use target range suggested in Hill and Sparling (2009) and Taylor (2011a). The number of sites sampled in the Ruamahanga whaitua area that did not meet the target range is as follows:

- One indicator - six sites sampled (50%);
- Two indicators - two sites (16%);
- Three indicators - one site (9%); and
- Four indicators - one sites (9%);

In the Kapiti whaitua area, for all the physical, chemical and trace element soil quality indicators, there were no sites out of 11 sites sampled had all soil indicators within the soil and/or the land use target range suggested in Hill and Sparling (2009) and Taylor (2011a). The number of sites sampled in the Kapiti whaitua area that did not meet the target range is as follows:

- One indicator - three sites sampled (28%);
- Two indicators - four sites (36%);
- Three indicators - one site (9%);
- Four indicators - two sites (18%); and
- Five indicators - one site (9%).

Physical and chemical soil quality indicator means for land use for the monitoring sites sampled are presented in Table 3.1. Results for individual soil quality monitoring sites are presented in Tables 3.2 to 3.5.

3.3 Soil physical properties

Mean soil bulk density for all cropping and pasture sites was 1.30Mg/m^3 and 1.34Mg/m^3 for market garden sites (Table 3.1). Mean bulk density for the soil orders was generally similar being 1.25 Mg/m^3 on Gley Soils, 1.27 Mg/m^3 on Brown Soils, 1.35 Mg/m^3 on Pallic Soils and 1.39 Mg/m^3 on Recent Soils. Across the region, seventeen out of 23 sites sampled (74%) had bulk density within the soil target range (Table 3.2 and Table 3.3) suggested by Hill and Sparling (2009).

Mean soil macroporosity for all cropping sites was 9.3% v/v, 14.6% v/v for market gardens and 4.2% v/v for pastoral sites (Table 3.1). Mean macroporosity for the soil orders was generally similar being with Pallic Soils (8.1% v/v), Gley Soils (10.2% v/v), Recent Soils (10.8% v/v), and Brown Soils (11.1 v/v). There were three sites with macroporosity values <2.5% v/v, which is considered to be very low (Drewry et al. 2008; Hill and Sparling (2009). Across the region, fifteen out of 23 sites sampled had macroporosity values within the target range for pasture suggested by Hill and Sparling (2009), (Table 3.2 and Table 3.3).

3.4 Soil chemical properties

Mean soil pH was 6.2 on cropping sites, 6.4 on market garden sites and 5.9 on pastoral sites (Table 3.1). All sites had soil pH within the target range suggested by Hill and Sparling (2009).

Mean soil carbon was 2.6% on cropping sites, 2.2% on market garden sites and 3.0% on pastoral sites (Table 3.1). Mean soil carbon was greatest for Gley Soils (3.1%) and least for Recent Soils (1.9%). Eight of the 23 sites across the region did not meet the total carbon levels within the target range suggested by Hill and Sparling (2009), (Table 3.2 and Table 3.3).

Two sites (Table 3.3) did not meet the total nitrogen target range suggested by Hill and Sparling (2009). It needs to be noted however, that cropping and horticulture (and therefore market gardening) is currently excluded in the suggested target range. The C:N ratio ranged from 9 to 14.

Mean soil anaerobic mineralisable nitrogen was lowest on market garden sites (33mg/kg), 64mg/kg on cropping sites and 104mg/kg on pastoral sites (Table 3.1). Two of the 23 sites across the region did not meet the anaerobic mineralisable nitrogen target range suggested by Hill and Sparling (2009), (Table 3.2 and Table 3.3).

Mean soil Olsen P was greatest on market garden sites (140mg/kg), 71mg/kg on pastoral sites and 49mg/kg on cropping sites. Olsen P was highly variable ranging from 17-95mg/kg on cropping sites, 41-196mg/kg on market garden sites and 22-142 mg/kg on pastoral sites. Eighteen of the 23 sites across the region did not meet (ie, exceeded) the Olsen P target range suggested by Taylor (2011a), (Table 3.2 and Table 3.3). Note that these results are expressed on a gravimetric basis. Some caution should be applied if comparing with some guidelines or volumetric laboratory methods. Regardless, Olsen P values are very high at some sites, particularly market gardens.

Olsen P was also calculated on a volumetric basis, using the undisturbed field bulk density measurements and the gravimetrically determined Olsen P values. When calculated on a volumetric basis, using the undisturbed field bulk density measurements, the calculated soil Olsen P values ranged from 26-309mg/L so some caution may need to be applied using this approach (see Drewry et al. 2013 for further details). Vegetable production targets also vary. Vegetable production Olsen P targets, for example, reported by Clarke et al. (1986) vary depending on soil P retention properties. For average values of P retention, Clarke et al. (1986) recommended an Olsen P value of 36-55mg/L for legumes, 46-55mg/L for brassicas, and 36-75mg/L for spinach and silverbeet. Targets in Taylor (2011a) also account for environmental effects.

3.5 Soil trace elements

Trace element (total recoverable) concentrations in samples from soil monitoring sites were below the NZWWA (2003) guidelines (Table 3.4). All sites had cadmium concentrations less than the MAF (2011) TFMS tier 1 trigger value of 0.6mg/kg (Table 3.4). One market garden site had a copper value approaching the NZWWA (2003) guideline value (Table 3.4).

3.6 Soil aggregate stability

Fourteen of the 23 sites across the region did not meet the aggregate stability target recommended by Plant and Food Research (Table 3.5). These sites were from cropping and market garden sites. Mean aggregate stability, as measured by the mean of percentage of aggregates >1 mm, was lowest on market garden sites (14.5%), 44.8% on cropping sites, and 68% on pastoral sites. Six market garden sites had very low values of percentage of aggregates >1 mm (<10%).

Mean aggregate stability, as measured by Mean Weight Diameter of aggregates (mm), was lowest on market garden sites (0.6mm), 1.29mm on cropping sites, and 1.84mm on pastoral sites. Six market garden sites had very low values of Mean Weight Diameter of aggregates (<0.5mm; Table 3.5).

Table 3.1: Physical and chemical soil quality indicators for land use. Means and standard deviations (SD) are presented.

Land use	N	Bulk density (Mg/m^3)		Macroporosity (-10kPa % v/v)		pH		Organic carbon (%)		Total N (%)		Anaerobic mineralisable-N (mg/kg)		Olsen P (mg/kg)	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Cropping	9	1.30	0.17	9.3	6.7	6.2	0.34	2.6	0.71	0.27	0.06	64	22	49	28
Market Garden	9	1.34	0.18	14.6	6.8	6.4	0.46	2.2	1.12	0.21	0.07	33	17	140	57
Pasture	5	1.30	0.11	4.2	3.0	5.9	0.23	3.0	0.55	0.29	0.05	104	11	71	50

Table 3.2: Physical and chemical results for individual sites in Ruamahanga whaitua area. Values in bold are outside the target range.

Site Name	Land use	Soil Order	Bulk density (Mg/m^3)	Macroporosity (-10kPa % v/v)	pH	Total carbon (%)	Total N (%)	Anaerobic mineralisable-N (mg/kg)	Olsen P (mg/kg)
GW016	Pasture	Gley	1.22	**4.7**	5.8	3.22	0.31	99.1	**49**
GW017	Cropping	Pallic	1.27	8.9	5.8	3.02	0.28	92.6	**36**
GW021	Pasture	Gley	1.26	**2.0**	5.6	3.80	0.37	122	**39**
GW022	Cropping	Recent	1.24	13.9	6.1	2.34	0.26	78.7	**95**
GW031	Cropping	Pallic	1.22	9.9	6.0	2.91	0.30	75	32
GW071	Cropping	Gley	1.21	9.7	6.4	2.84	0.29	48.4	**86**
GW075	Market Garden	Recent	1.18	27.0	5.8	2.33	0.22	65.2	**53**
GW079	Cropping	Gley	**1.61**	**0.5**	6.9	**1.66**	0.18	30.5	**69**
GW080	Cropping	Recent	**1.53**	**1.6**	6.1	**1.50**	0.16	30.0	17
GW082	Cropping	Gley	1.11	22.8	6.2	3.78	0.36	69.0	**48**
GW085	Cropping	Gley	1.14	11.4	6.1	2.81	0.31	81.1	25
GW086	Cropping	Gley	1.34	**5.1**	5.8	2.97	0.32	71.2	35
Target range									
Pallic and Recent soil			0.4-1.4						
Other soils			0.7-1.4			2.5->12			
Recent soil						2->12			
Pasture				6-30	5-6.6		0.25-0.70	20-250	
Pasture, hort & cropping sedimentary soil									20-35
Cropping/horticulture				6-30	5-7.6		Exclusion	20-200	
Number of sites not meeting target			2/12	5/12	0/12	2/12	0/2	0/12	8/12

Table 3.3: Physical and chemical results for individual sites in Kapiti whaitua area. Values in bold are outside the target range.

Site Name	Land use	Soil Order	Bulk density (Mg/m^3)	Macroporosity (-10kPa % v/v)	pH	Total carbon (%)	Total N (%)	Anaerobic mineralisable-N (mg/kg)	Olsen P (mg/kg)
GW027	Pasture	Recent	1.26	9.1	6.1	2.60	**0.24**	107	**102**
GW044	Pasture	Brown	1.30	**2.6**	5.7	2.83	0.29	102	22
GW087	Pasture	Recent	**1.49**	**2.5**	6.2	2.43	**0.24**	90.9	**142**
GW090	Market Garden	Brown	1.15	16.9	6.4	2.91	0.30	46.5	**41**
GW092	Market Garden	Gley	1.24	18.4	6.9	**2.05**	0.21	33.0	**162**
GW093	Market Garden	Recent	**1.49**	7.7	6.4	**1.30**	0.14	20.4	**130**
GW094	Market Garden	Recent	1.35	16.8	6.1	**1.49**	0.17	22.9	**194**
GW107	Market Garden	Recent	**1.57**	7.4	6.4	**1.40**	0.15	**16.2**	**196**
GW108	Market Garden	Gley	1.12	17.5	5.9	4.81	0.35	38.3	**159**
GW111	Market Garden	Brown	1.35	13.9	7.3	**1.32**	0.14	39.3	**184**
GW112	Market Garden	Pallic	**1.57**	**5.6**	6.6	**2.07**	0.20	**12.0**	**138**
Target range									
Pallic and Recent soil			0.4-1.4						
Other soils			0.7-1.4			2.5->12			
Recent soil						2->12			
Pasture				6-30	5-6.6		0.25-0.70	20-250	
Pasture, hort & cropping sedimentary soil									20-35
Cropping/horticulture				6-30	5-7.6		Exclusion	20-200	
Number of sites not meeting target			4/11	3/11	0/11	6/11	2/3	2/11	10/11

Table 3.4: Trace element concentrations (total recoverable) for individual sites

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	Pasture	11	0.27	26	24	34	22	105
GW017	Cropping	2	0.19	11	5	10.2	4	32
GW021	Pasture	3	0.13	21	12	21	14	84
GW022	Cropping	7	0.17	18	16	18	14	87
GW027	Pasture	8	0.25	17	32	23	15	91
GW031	Cropping	< 2	0.2	8	3	6.9	4	35
GW044	Pasture	6	0.14	17	13	16.5	13	74
GW071	Cropping	2	0.21	18	7	10.2	13	60
GW075	Market Garden	4	< 0.10	16	12	13.6	12	59
GW079	Cropping	8	0.27	22	20	27	20	94
GW080	Cropping	7	< 0.10	21	18	24	18	86
GW082	Cropping	4	0.16	10	3	16.4	3	33
GW085	Cropping	7	0.15	22	17	22	19	91
GW086	Cropping	3	0.2	19	10	16.3	15	91
GW087	Pasture	6	0.32	16	49	23	14	92
GW090	Market Garden	4	0.25	22	16	18.3	14	89
GW092	Market Garden	8	0.25	22	20	38	16	111
GW093	Market Garden	8	0.18	17	29	30	15	94
GW094	Market Garden	9	0.34	20	92	35	16	106
GW107	Market Garden	11	0.39	19	77	36	15	115
GW108	Market Garden	2	0.19	18	32	27	11	83
GW111	Market Garden	3	0.2	17	20	16	11	76
GW112	Market Garden	3	0.12	14	24	12	7	58
Target range		<20	<1	<600	<100	<300	<60	<300
Number of sites not meeting target		0	0	0	0	0	0	0
TFMS tier one trigger* (<0.6mg/kg)			0					

* Tiered Fertiliser Management System (TFMS) first tier trigger value (0.6mg/kg) as per the New Zealand Cadmium Management Strategy.

Table 3.5: Aggregate stability for individual sites. Values in bold are outside the target range.

Site	Land use	Kapiti or Ruamahanga	Average of Mean Weight Diameter of aggregates (mm)	Average of percentage of aggregates >1 mm
GW016	Pasture	Ruamahanga	1.75	62.5
GW017	Cropping	Ruamahanga	2.22	82.4
GW021	Pasture	Ruamahanga	1.73	63.9
GW022	Cropping	Ruamahanga	**0.67**	**18.0**
GW027	Pasture	Kapiti	2.01	76.5
GW031	Cropping	Ruamahanga	1.85	68.8
GW044	Pasture	Kapiti	2.11	78.9
GW071	Cropping	Ruamahanga	**1.10**	**37.4**
GW075	Market Garden	Ruamahanga	**1.14**	**37.8**
GW079	Cropping	Ruamahanga	**0.65**	**17.1**
GW080	Cropping	Ruamahanga	**0.84**	**25.5**
GW082	Cropping	Ruamahanga	1.58	58.0
GW085	Cropping	Ruamahanga	**1.18**	**41.0**
GW086	Cropping	Ruamahanga	1.50	55.3
GW087	Pasture	Kapiti	1.60	57.8
GW090	Market Garden	Kapiti	**1.32**	**46.2**
GW092	Market Garden	Kapiti	**0.40**	**5.8**
GW093	Market Garden	Kapiti	**0.29**	**1.6**
GW094	Market Garden	Kapiti	**0.48**	**9.4**
GW107	Market Garden	Kapiti	**0.27**	**0.8**
GW108	Market Garden	Kapiti	**0.33**	**2.7**
GW111	Market Garden	Kapiti	**0.84**	**24.7**
GW112	Market Garden	Kapiti	**0.29**	**1.3**

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References

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.

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. Occasional Report No. 26. Fertilizer and Lime Research Centre, 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.

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.

SINDI. 2010. *Soil quality indicators database.* http://sindi.landcareresearch.co.nz

Sorensen P. 2012. *Soil quality and stability in the Wellington region: State and trends.* Greater Wellington Regional Council, Publication No. GW/EMI-T-12/138, Wellington.

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 (SINDI 2010).

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 (SINDI 2010).

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 a 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).

Aggregate stability

Soil aggregates need to be of a size, shape and packing that maintains soil porosity for roots to easily access air, water and nutrients. Soils with high aggregate stability are better able to withstand the degradation that may result from cultivation, compaction and raindrop impact. Aggregates with low structural stability are more prone to dispersion and erosion by wind and water. Research at Plant and Food Research has shown that soil with low aggregate stability has lower crop yield than the regional average.

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 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 is available from Drewry et al. (2013).

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 from Hill and Sparling (2009) are no longer used. Updated targets from Taylor (2011a) 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 -10kPa)

	Very low	Low	Adequate	High	
Pastures, cropping and horticulture	0	**6**	10[1]	30	40
Forestry	0	**8**	10	30	40

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

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)

Land use	**Soil Type**	**Suggested Olsen P targets**
Pasture, Horticulture and cropping	Volcanic	20-50
Pasture, Horticulture and cropping	Sedimentary and Organic soils	20-35
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

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

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 Tina Harrison-Kirk, 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 %>1mm which is an indication of how stable the soil is. Soils below 1.5 MWD or 50% stability are at greater risk of producing less than the regional average yield.