greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao

Soil Quality State of the Environment monitoring programme

Annual data report, 2015/16

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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 2015 to 30 June 2016 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 22 sites including 13 dairy farms and 9 other land use sites. Of the 9 other land use sites, two were dairy runoff, and four sites had been dairy farms in earlier samplings. 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 (eg, Drewry et al. 2015.

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 two sites were sampled during 27 April to 2 May 2016 (Figure 2.1; Table 2.1). Sites sampled in the 2015/16 year comprised predominantly dairy pasture sites grazed by dairy cattle and dairy run-off sites.

The sites comprised 13 dairy farm sites, two dairy runoff sites, six beef, drystock or other crop/grazing sites, and one tree nursery. Of the 22 sites, four of the currently non-dairy sites had been used for dairying in earlier samplings or in the original first sampling. There were 13 sites in the Ruamahanga catchment area (whaitua) region, and nine in the Kapiti Coast whaitua area.

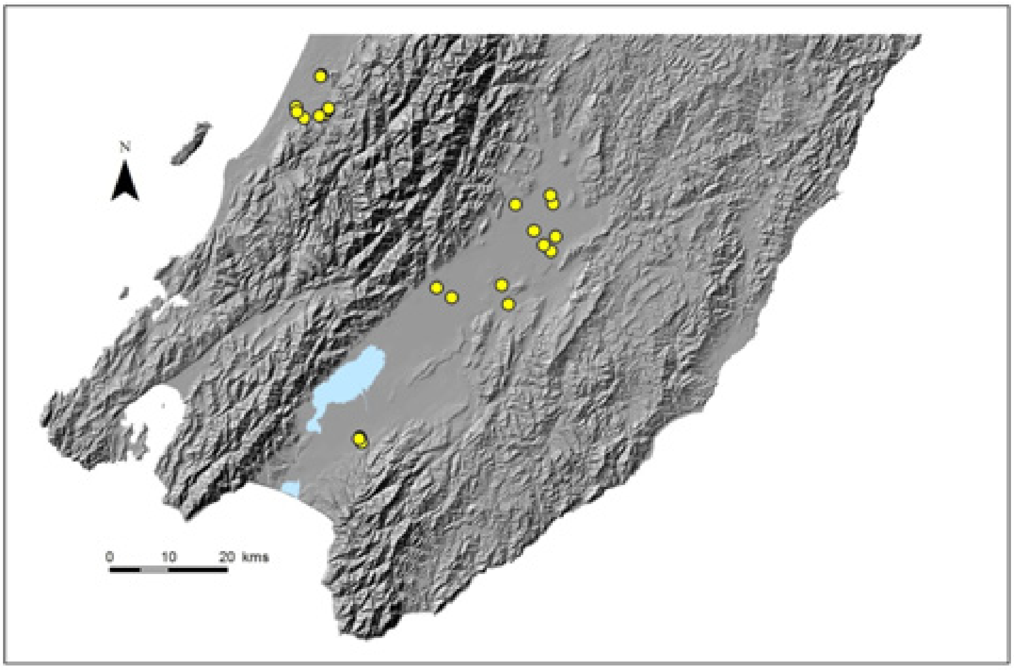

Figure 2.1: Greater Wellington's soil quality monitoring sites sampled in 2015/16

A range of soil orders were sampled. Details of the soil order, group, subgroup, soil type 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).

Four soil orders were sampled including 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).

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

Site	Soil Order	Soil subgroup	Soil type	Land use in 2016
GW005	Brown	Acidic Allophanic Brown	Kawhatau stony silt loam	Dairy runoff
GW006	Brown	Mottled Orthic Brown	Te Horo silt loam	Beef drystock. Previously dairy, but not for about 9 years
GW010	Recent	Acidic-weathered Fluvial Recent	Manawatu fine sandy loam	Dairy
GW015	Gley	Typic Recent Gley	Ahikouka silty clay	Dairy
GW019	Pallic	Argillic Perch-gley Pallic	Kokotau silt loam	Dairy
GW023	Recent	Acidic-weathered Fluvial Recent	Greytown silt loam	Cattle drystock grazing. Originally dairy until about 2002
GW032	Pallic	Typic Perch-gley Pallic	Bideford silt loam	Dairy
GW036	Pallic	Typic Perch-gley Pallic	Moroa silt loam	Dairy
GW038	Pallic	Typic Argillic Pallic	Tauherenikau silt loam	Dairy
GW042	Pallic	Typic Immature Pallic	Moroa silt loam	Drystock, paddock in young crop
GW046	Gley	Acidic Orthic Gley	Rahui silt loam.	Dairy
GW048	Recent	Acidic Fluvial Recent	Otaki gravelly silt loam	Dairy (including effluent)
GW076	Pallic	Mottled Immature Pallic	Tauherenikau silt loam	Dairy runoff. New grass, previously barley
GW078	Recent	Weathered Fluvial Recent	Greytown silt loam	Dairy
GW096	Recent	Weathered Fluvial Recent	Greytown silt loam	Poplar tree nursery, previously dairy before 2013
GW098	Pallic	Typic Perch-gley Pallic	Moroa silt loam	Dairy
GW103	Pallic	Typic Immature Pallic	Tauherenikau gravelly sandy loam	Cattle drystock
GW105	Pallic	Mottled Argillic Pallic	Kokotau silt loam	Dairy
GW109	Brown	Typic Orthic Brown	Ashhurst stony silt loam	Dairy
GW115	Brown	Typic Orthic Brown	Te Horo silt loam	Drystock pasture but previously dairy
GW116	Brown	Acid Orthic Brown	Hautere stony silt loam	Dairy
GW117	Brown	Mottled Orthic Brown	Te Horo silt loam	Cattle drystock grazing

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 matric potential of -10kPa. Ambiguity may arise with other terms (e.g. air-filled porosity) or macroporosity measured at other matric potentials (Drewry et al. 2008; 2015).

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 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 has resulted in inconsistency and a lack of clarity around protection of ecological receptors (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.

Note that as at 2016, the biosolids guidelines described above, are being updated.

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. 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 use and soil orders 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 and trace element soil quality indicators, three out of 22 sites sampled (14%) had all soil indicators within the soil and/or the land use target range described above. In contrast, for all the physical, chemical and trace element soil quality indicators, 19 out of 22 sites sampled (86%) 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 nil, one, two or three indicators (including trace elements) 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	14
1	8	36
2	10	45
3	1	5

Physical and chemical soil quality indicator mean values for the predominant land use and soil orders 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 5.9 on the dairy land use sites and 5.8 on non-dairy sites sampled (Table 3.2). All sites had soil pH within the target range. Mean soil carbon was 5.5% on dairy land use sites sampled. Mean soil carbon was greatest for Brown Soils (7.5%) and least for Recent Soils (4.3%). There were no sites across the region did not meet the total carbon levels within the target range. Mean total nitrogen was 0.55% on dairy land use sites sampled. Seven sites did not meet the total nitrogen target range. The C:N ratio ranged from 9.2 to 11.7

Mean soil anaerobic mineralisable nitrogen was similar for dairy and non-dairy sites. Brown Soils had greater mean anaerobic mineralisable nitrogen than Pallic Soils, while Recent Soils had the lowest anaerobic mineralisable nitrogen mean values. There were no sites across the region did not meet the anaerobic mineralisable nitrogen target range.

Mean soil Olsen P was similar for dairy (64 mg/kg) and non-dairy (65 mg/kg) sites. Olsen P was highly variable ranging from 28-150 mg/kg over all the sites. Eighteen of the 22 sites across the region did not meet (i.e., were less than or exceeded) 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.

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 31-170 mg/L. One site had a calculated Olsen P value of >100 mg/L. Some caution may need to be applied when comparing values. See Drewry et al. (2013; 2015) for further details and explanation. Note that an Olsen P value of 40 mg/L (commercial volumetric method) is the recommended industry upper limit guideline for sedimentary soils for the top 25% of dairy farms in a region (Roberts and Morton 2009).

Mean soil bulk density for dairy pasture sites was 1.15 Mg/m^3 (Table 3.2). Mean bulk density for the soil orders was 0.94 Mg/m^3 on Brown Soils, 1.16 Mg/m^3 on Pallic Soils, and 1.20 Mg/m^3 on Recent Soils. Across the region, all sites except one had bulk density within the soil target range.

Mean soil macroporosity for all dairy sites was 8.7% v/v and 14.3% v/v for non-dairy land use sites (Table 3.2). Mean macroporosity for the soil orders was lowest for the Pallic Soil sites (9.0% v/v). There was one site with macroporosity values of 2.3% v/v, which is considered to be very low (Drewry et al. 2008; Hill and Sparling 2009). Across the region, five out of 22 sites sampled had macroporosity values below the recommended target range.

Table 3.2: Chemical and physical soil quality indicators for land use and soil order for the region. Means and standard deviations (SD) are presented.

Land use	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)	
			Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd	Mean	sd
Dairy only	All	13	5.9	0.24	5.5	2.0	0.55	0.18	229	78	64	22	1.15	0.16	8.7	5.4
Non dairy	All	9	5.8	0.42	6.4	2.7	0.6	0.22	217	93	65	36	1.03	0.18	14.3	5.1
All	Brown	6	5.8	0.49	7.5	2.9	0.69	0.22	267	74	84	38	0.94	0.14	15.8	4.7
All	Pallic	9	5.9	0.32	5.6	2.1	0.55	0.18	203	71	54	22	1.16	0.17	9.0	6.3
All	Recent	5	5.9	0.17	4.3	1.3	0.4	0.10	161	41	61	17	1.2	0.13	10.8	4.1

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 the physical, chemical and trace element soil quality indicators, three out of 13 sites sampled (23%) had all soil indicators within the soil and/or the land use target range described above. In contrast, 10 out of 13 sites sampled (77%) 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 nil, one or two indicators (including trace elements) outside target range in Ruamahanga whaitua

Number of Indicators and trace elements outside range	Number of sites	Percentage of sites within the whaitua area that have indicators and trace elements outside target range
0	3	23
1	3	23
2	6	46
3	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, soil carbon, and anaerobic mineralisable nitrogen within the target range. Olsen P was variable ranging from 28-84 mg/kg over the whaitua sites. Nine of the 13 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.

All Ruamahanga whaitua sites except one had bulk density within the soil target range. There was one site with macroporosity values of 2.3% v/v, which is considered to be very low (Drewry et al. 2008; Hill and Sparling 2009). Across the whaitua, four 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 such as NZWWA (2003) guidelines. All sites had cadmium concentrations less than the MAF (2011) TFMS trigger value of 1.0 mg/kg. One site 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).

Table 3.4: Chemical and physical results for individual sites in Ruamahanga whaitua. Values in colour are outside the target range.

Site Name	Land use	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)
GW015	Dairy	Gley	6.0	6.8	0.73	353	80	1.00	7.7
GW019	Dairy	Pallic	5.8	3.5	0.34	127	71	1.35	4.3
GW023	Drystock	Recent	6.1	6.5	0.60	188	82	1.01	16.2
GW032	Dairy	Pallic	6.0	3.2	0.34	128	34	1.41	4.8
GW036	Dairy	Pallic	6.1	5.4	0.54	239	28	1.13	7.9
GW038	Dairy	Pallic	5.7	6.8	0.66	253	64	1.08	5.8
GW042	Drystock	Pallic	5.5	8.3	0.76	251	81	0.91	21.3
GW076	Dairy runoff	Pallic	5.6	3.8	0.40	107	28	1.16	17.1
GW078	Dairy	Recent	5.8	3.9	0.40	161	53	1.23	6.6
GW096	Nursery	Recent	5.7	3.1	0.32	90	36	1.37	6.9
GW098	Dairy	Pallic	6.3	4.0	0.38	166	44	1.32	7.6
GW103	Drystock	Pallic	5.5	8.3	0.74	253	48	0.99	10.0
GW105	Dairy	Pallic	6.2	6.9	0.75	301	84	1.05	2.3
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			>6
Pasture on sedimentary soils							20-40		
Number of sites not meeting target			0/13	0/13	4/13	0/13	9/13	1/13	4/13

Table 3.5: Trace element concentrations (total recoverable) for individual sites in Ruamahanga whaitua. Values in colour are outside the target range.

Site Name	Land use	Soil Order	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)
GW015	Dairy	Gley	7	0.6	21	23	29	16	92
GW019	Dairy	Pallic	< 2	0.25	8	6	8.9	5	48
GW023	Drystock	Recent	6	0.35	19	16	28	16	87
GW032	Dairy	Pallic	3	0.4	13	7	7.4	9	45
GW036	Dairy	Pallic	5	0.44	19	13	17.7	15	91
GW038	Dairy	Pallic	5	0.49	18	12	18	12	85
GW042	Drystock	Pallic	4	0.46	13	10	18.2	8	63
GW076	Dairy runoff	Pallic	4	0.26	19	15	18.6	16	87
GW078	Dairy	Recent	5	0.35	18	14	14.8	17	74
GW096	Nursery	Recent	7	0.29	20	17	21	18	83
GW098	Dairy	Pallic	3	0.26	9	6	10	5	32
GW103	Drystock	Pallic	4	0.36	17	7	16.9	10	64
GW105	Dairy	Pallic	6	0.63	22	24	20	17	85
Target or guideline range			<20	<1	<600	<100	<300	<60	<300
Number of sites not meeting guideline			0/13	0/13	0/13	0/13	0/13	0/13	0/13
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				1/13					
Eco-SGV agricultural land typical soil (Brown)			20	1.5	300	150	530		190
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 Eco-SGV for aged typical and sensitive reference soil									

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

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 were no sites 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 3.6.

Table 3.6: Number of sites with nil, one or two indicators (including trace elements) outside target range in Kapiti whaitua

Number of Indicators and trace elements outside range	Number of sites	Percentage of sites within the whaitua area that have indicators and trace elements outside target range
0	0	0
1	5	56
2	4	44

Results for individual soil quality monitoring sites for soil chemical and physical properties for the Kapiti whaitua are presented in Table 3.7. All Kapiti whaitua sites had soil pH, soil carbon, and anaerobic mineralisable nitrogen within the target range. Olsen P was variable ranging from 47-150 mg/kg over Kapiti sites. All the nine 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.

All Kapiti whaitua sites had bulk density within the soil target range. Across the whaitua, one site sampled had its macroporosity value below the recommended target range. Results for individual soil quality monitoring sites for trace elements for the whaitua are presented in 3.8. 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. Two sites 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).

Table 3.7: Chemical and physical results for individual sites in Kapiti whaitua. Values in colour are outside the target range.

Site Name	Land use	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)
GW005	Dairy runoff	Brown	5.4	11.8	1.01	388	56	0.75	20.0
GW006	Drystock	Brown	6.6	5.3	0.52	249	150	1.13	7.7
GW010	Dairy	Recent	5.9	4.0	0.42	180	71	1.20	12.7
GW046	Dairy	Gley	6.0	5.2	0.53	352	47	1.13	4.4
GW048	Dairy	Recent	5.9	3.8	0.41	185	60	1.27	11.5
GW109	Dairy	Brown	5.6	9.8	0.87	276	95	0.88	20.1
GW115	Drystock	Brown	6.2	5.7	0.60	274	59	0.89	15.0
GW116	Dairy	Brown	5.5	7.8	0.73	261	96	0.95	17.8
GW117	Drystock	Brown	5.4	4.5	0.42	156	48	1.05	14.2
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			>6
Pasture on sedimentary soils							20-40		
Number of sites not meeting target			0/9	0/9	3/9	0/9	9/9	0/9	1/9

Table 3.8: Trace element concentrations (total recoverable) for individual sites in Kapiti whaitua. Values in colour are outside the target range.

Site Name	Land use	Soil Order	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)
GW005	Dairy runoff	Brown	4	0.62	14	10	11.5	5	60
GW006	Drystock	Brown	5	0.35	19	21	16	12	101
GW010	Dairy	Recent	6	0.44	19	19	20	18	97
GW046	Dairy	Gley	3	0.43	15	25	14.7	12	76
GW048	Dairy	Recent	6	0.28	16	16	18.2	15	85
GW109	Dairy	Brown	2	0.51	8	16	8.5	3	41
GW115	Drystock	Brown	5	0.71	19	21	12.9	13	89
GW116	Dairy	Brown	4	0.4	15	14	15.5	10	84
GW117	Drystock	Brown	4	0.32	15	11	17.7	10	64
Target or guideline range			<20	<1	<600	<100	<300	<60	<300
Number of sites not meeting guideline			0/9	0/9	0/9	0/9	0/9	0/9	0/9
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				2/9					
Eco-SGV agricultural land typical soil (Brown)			20	1.5	300	150	530		190
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 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.

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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 -10kPa. Macroporosity is the percentage of pores > 30 microns in diameter, when measured at -10kPa. 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.

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 -10kPa)

	Very low	Low	Adequate	High	
Pastures, cropping and horticulture	0	**6**	10	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

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

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