greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao

Soil quality State of the Environment monitoring programme

Annual data report, 2012/13

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1. Introduction

This report summarises the key results from the Soil quality State of the Environment (SoE) monitoring programme for the period 1 July 2012 to 30 June 2013 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 15 dairy farms and 8 other land use sites. As a data report it is not the intention to provide an in-depth discussion of results or implications.

2. Overview of Soil quality 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 (Figure 2.1). 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.

2.3 Monitoring sites

Twenty three sites were sampled during 8 to 13 May 2013 (Figure 2.1; Table 2.1). Sites sampled in the 2012/13 year comprised; 15 dairy farm sites (including one effluent paddock site), one dairy runoff, four beef or other grazing, one new house development, one site previously use for cropping and one tree nursery. Several of the non-dairy sites had been used for dairying previously.

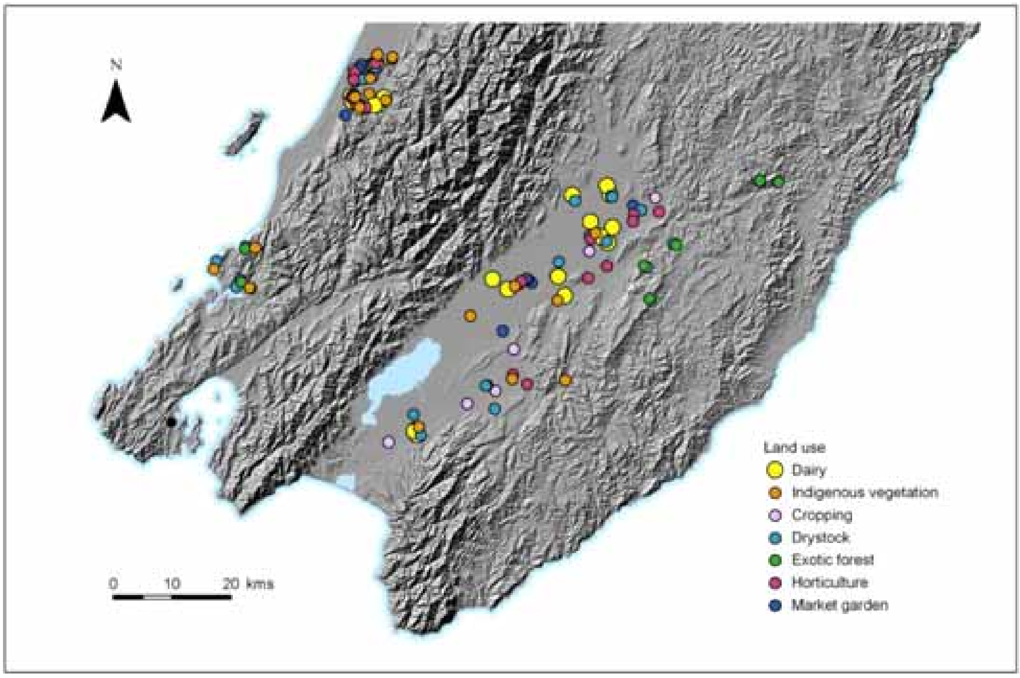

Figure 2.1: Greater Wellington's soil quality monitoring sites. Most of the 23 sites sampled in the 2012/13 year are used for dairying.

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. 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).

2.3.1 Soil sampling methods

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, group, subgroup, and soil type for sites sampled in 2012/13

Site	Soil Order	Soil subgroup	Soil type	Land use
GW005	Brown	Acidic Allophanic Brown	Kawhatau stony silt loam	Dairy runoff
GW006	Brown	Mottled Orthic Brown	Te Horo silt loam	Beef. Was dairy, but not dairy for about 6 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/beef grazing
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, lambs and hay
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	Recent new grass, previously crop
GW078	Recent	Weathered Fluvial Recent	Greytown silt loam	Dairy
GW096	Recent	Weathered Fluvial Recent	Greytown silt loam	Poplar tree nursery (Akura), was dairy in previous samplings
GW097	Recent	Weathered Fluvial Recent	Greytown silt loam	Drystock but now new housing
GW098	Pallic	Typic Perch-gley Pallic	Moroa silt loam	Dairy
GW103	Pallic	Typic Immature Pallic	Tauherenikau gravelly sandy loam	Cattle and dairy runoff grazing
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	Dairy
GW116	Brown	Acid Orthic Brown	Hautere stony silt loam	Dairy
GW117	Brown	Mottled Orthic Brown	Te Horo silt loam	Dairy

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).

2.3.2 Soil analytical methods

The soil analytical methods are presented in Appendix 2. Further details on laboratory methods are presented in Land Monitoring Forum (2009).

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)

2.4 Monitoring indicators

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, why they are important and details of field and 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

3. Soil quality

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).

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 Results

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. New Olsen P target ranges reported in Taylor (2011a) are used.

For all the physical, chemical and trace element soil quality indicators, four out of 23 sites sampled (17%) had all soil indicators within the soil and/or the land use target range suggested in Hill and Sparling (2009) and Taylor (2011a). A further eight sampled (35%) had one indicator that did not meet the soil and land use target range, six sites (26%) had two indicators that did not meet the soil and land use target range, and five sites (22%) had three indicators that did not meet the soil and land use target range.

Physical and chemical soil quality indicator means for land use and soil orders for the monitoring sites sampled are presented in Table 3.1 and Table 3.2, respectively. Results for individual soil quality monitoring sites are presented in Tables 3.3 to 3.5.

3.2.1 Soil physical properties

Mean soil bulk density for all dairy sites was 1.11Mg/m^3 and 1.03Mg/m^3 for non dairy sites (Table 3.1). Mean bulk density under dairying land use was greater on Recent Soils and Pallic Soils than the Brown and Gley Soils (Table 3.2). Twenty two out of 23 sites sampled (96%) had bulk density within the soil target range (Table 3.3) suggested by Hill and Sparling (2009).

Mean soil macroporosity for all dairy sites was 7% v/v and 14.8% v/v for non dairy sites (Table 3.1). Mean macroporosity for dairy sites was greatest on Brown Soils (9.9% v/v) and lowest on Gley Soils (4.3% v/v). There were three dairy sites with macroporosity values <2.5% v/v. Seventeen out of 23 sites sampled had macroporosity values within the target range for pasture suggested by Hill and Sparling (2009), (Table 3.3).

3.2.2 Soil chemical properties

Mean soil pH was 6.1 on dairy sites and was 6.0 on non dairy sites (Table 3.1). With one exception all sites had soil pH within the target range suggested by Hill and Sparling (2009).

Mean soil carbon on dairy sites was 4.4% and was 6.7% for non dairy sites (Table 3.1). Mean soil carbon was greatest for Brown Soils for both dairy and non dairy sites and least for Recent Soils (Table 3.2). All sites (Table 3.4) had total carbon levels within the target range for soils suggested by Hill and Sparling (2009).

Seven of the 23 sites (Table 3.4) did not meet the total nitrogen target range suggested by Hill and Sparling (2009). The C:N ratio ranged from 9 to 12. Two of the 23 sites did not meet the anaerobic mineralisable nitrogen target range suggested by Hill and Sparling (2009).

Mean soil Olsen P on dairy sites was 67mg/kg and 66mg/kg on non dairy sites. Olsen P was highly variable ranging from 23-161mg/kg (Table 3.4). Eighteen of the 23 sites did not meet (ie, exceeded) the Olsen P target range suggested by Taylor (2011a). Note that these results are expressed on a gravimetric basis. Some caution should be applied if comparing with some guidelines or volumetric laboratory methods.

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 24-187mg/L. On this calculated volumetric basis, 18 of the 23 sites exceeded an Olsen P value of 40mg/L. Five sites had calculated Olsen P values of 100mg/L or greater. Note that an Olsen P value of 40mg/L is the recommended industry upper limit guideline for sedimentary soils for the top 25% of dairy farms in a region (Roberts and Morton 2009).

3.2.3 Soil trace elements

Trace element (total recoverable) concentrations in samples from soil monitoring sites were below the NZWWA (2003) guidelines (Table 3.5).

Three sites however, had cadmium concentrations greater than the MAF (2011) TFMS tier 1 trigger value of 0.6mg/kg (Table 3.5). The MAF (2011) strategy indicates that once the trigger value of 0.6mg/kg is reached (ie, soil cadmium range 0.6-1.0mg/kg) then management recommendations include that application rates are restricted to asset of products and application rates to minimise cadmium accumulation.

Table 3.1: Physical and chemical soil quality indicators for dairy and non-dairy sites. Means and standard deviations (SD) are presented.

Land use	No. of sites	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	15	6.1	0.30	5.4	1.90	0.53	0.18	152	51	67	28	1.11	0.15	7.0	3.9
Non-dairy	8	6.0	0.40	6.7	3.17	0.61	0.26	161	70	66	46	1.03	0.17	14.8	5.5

Table 3.2: Physical and chemical soil quality indicators by soil order for dairy and non-dairy sites. Means and standard deviations (SD) are presented.

Land use	Soil Order	No. of sites	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	Brown	4	5.8	0.45	7.0	2.39	0.67	0.20	185	66	80	25	1.01	0.13	9.9	3.2
Dairy	Gley	2	6.2	0.16	5.8	1.26	0.60	0.15	177	21	77	44	1.03	0.01	4.3	4.0
Dairy	Pallic	6	6.1	0.20	4.9	1.61	0.48	0.17	138	45	53	30	1.17	0.18	6.7	4.4
Dairy	Recent	3	6.2	0.08	4.0	0.17	0.41	0.02	116	36	71	10	1.19	0.06	5.8	3.1
Non-dairy	Brown	2	6.2	0.84	8.5	4.84	0.77	0.37	209	55	118	61	0.95	0.30	14.0	10.0
Non-dairy	Pallic	3	5.8	0.09	7.4	3.23	0.67	0.26	167	100	42	14	0.98	0.14	18.3	2.2
Non-dairy	Recent	3	6.0	0.35	4.8	1.93	0.45	0.16	121	33	57	39	1.14	0.11	11.7	4.2

Table 3.3: Physical results for individual sites. Values in bold are outside the target range.

Site Number	Land use	Soil Order	Bulk density (Mg/m^3)	Macroporosity (-10kPa % v/v)
GW005	Dairy runoff	Brown	0.74	21.0
GW006	Beef	Brown	1.16	6.9
GW010	Dairy	Recent	1.12	9.3
GW015	Dairy	Gley	1.02	**1.5**
GW019	Dairy	Pallic	**1.45**	**2.0**
GW023	Cattle/beef grazing	Recent	1.10	7.9
GW032	Dairy	Pallic	1.23	11.9
GW036	Dairy	Pallic	1.07	11.9
GW038	Dairy	Pallic	1.02	**5.8**
GW042	Drystock	Pallic	0.96	18.6
GW046	Dairy	Gley	1.03	7.1
GW048	Dairy (incl effluent)	Recent	1.18	**3.7**
GW076	Previously crop	Pallic	1.13	20.4
GW078	Dairy	Recent	1.25	**4.4**
GW096	Poplar tree nursery	Recent	1.26	11.1
GW097	Drystock now housing	Recent	1.04	16.2
GW098	Dairy	Pallic	1.27	6.3
GW103	Cattle and dairy grazing	Pallic	0.86	16.0
GW105	Dairy	Pallic	0.97	**2.3**
GW109	Dairy	Brown	0.95	9.5
GW115	Dairy	Brown	0.93	8.9
GW116	Dairy	Brown	0.96	14.3
GW117	Dairy	Brown	1.21	6.8
Target range (Pallic and Recent soils)			*0.4-1.4*	
Target range (other soils)			*0.7-1.4*	
Target range (pasture)				*6-30*
Number of sites not meeting target range			1/23	6/23

Table 3.4: Chemical results for individual sites. Values in bold are outside the target range.

Site Number	Land use	Soil Order	pH	Total carbon (%)	Total N (%)	Anaerobic mineralisable-N (mg/kg)	Olsen P (mg/kg)
GW005	Dairy runoff	Brown	5.6	11.9	**1.03**	248	**75**
GW006	Beef	Brown	**6.8**	5.1	0.51	170	**161**
GW010	Dairy	Recent	6.3	3.9	0.40	135	**71**
GW015	Dairy	Gley	6.4	6.7	**0.71**	192	**108**
GW019	Dairy	Pallic	5.9	3.9	0.37	150	**74**
GW023	Cattle/beef grazing	Recent	6.4	6.1	0.56	143	**100**
GW032	Dairy	Pallic	6.3	2.7	0.28	57	34
GW036	Dairy	Pallic	6.1	5.2	0.53	157	23
GW038	Dairy	Pallic	5.9	6.5	0.61	166	31
GW042	Drystock	Pallic	5.7	8.0	**0.72**	182	**52**
GW046	Dairy	Gley	6.1	4.9	0.50	162	**46**
GW048	Dairy (incl effluent)	Recent	6.2	4.2	0.44	139	**81**
GW076	Previously crop	Pallic	5.9	3.9	0.39	61	26
GW078	Dairy	Recent	6.2	3.9	0.39	75	**62**
GW096	Poplar tree nursery	Recent	5.8	2.6	0.27	84	24
GW097	Drystock now housing	Recent	5.8	5.7	0.52	137	**47**
GW098	Dairy	Pallic	6.0	3.9	0.37	119	**53**
GW103	Cattle and dairy grazing	Pallic	5.9	10.3	**0.90**	**259**	**47**
GW105	Dairy	Pallic	6.4	6.8	**0.73**	181	**102**
GW109	Dairy	Brown	5.9	9.1	**0.84**	**275**	**105**
GW115	Dairy	Brown	6.4	5.7	0.61	157	**78**
GW116	Dairy	Brown	5.5	9.0	**0.82**	187	**91**
GW117	Dairy	Brown	5.4	4.3	0.40	120	**47**
Target range (other soils)				*2.5->12*			
Target range (Recent soils)				*2.0->12*			
Target range (pasture)			*5-6.6*		*0.25-0.7*	*20-250*	
Target range (pasture on sedimentary soils)							*20-35*
Number of sites not meeting target range			1/23	0/23	7/23	2/23	18/23

Table 3.5: Trace element concentrations (total recoverable) for individual sites

Site Number	Land use	Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/kg)	Zinc (mg/kg)
GW005	Dairy runoff	4	0.68	14	9	11.9	5	62
GW006	Beef	5	0.43	19	19	14.9	10	94
GW010	Dairy	5	0.38	17	19	19.1	15	86
GW015	Dairy	5	0.56	19	19	19.1	14	85
GW019	Dairy	<2	0.27	8	5	8	2	24
GW023	Cattle/beef grazing	5	0.46	18	19	34	14	104
GW032	Dairy	<2	0.27	13	6	7.9	7	45
GW036	Dairy	3	0.32	16	9	14.4	11	70
GW038	Dairy	3	0.38	16	10	16.6	11	72
GW042	Drystock	4	0.27	13	9	17.2	7	54
GW046	Dairy	<2	0.23	12	14	11.6	6	50
GW048	Dairy (incl effluent)	5	0.34	17	18	20	15	83
GW076	Previously crop	4	0.22	18	13	19.6	14	80
GW078	Dairy	4	0.24	17	12	13.9	14	66
GW096	Poplar tree nursery	6	0.26	20	18	22	19	86
GW097	Drystock, housing	3	0.23	15	9	12	10	59
GW098	Dairy	2	0.2	9	6	9.9	4	35
GW103	Cattle, dairy grazing	3	0.31	14	6	13.7	6	52
GW105	Dairy	4	0.63	20	23	19.7	15	91
GW109	Dairy	2	0.5	10	10	8.3	3	52
GW115	Dairy	3	0.64	16	21	13.3	10	82
GW116	Dairy	3	0.34	14	11	16	7	79
GW117	Dairy	3	0.23	15	9	17.8	9	62
Target range		*<20*	*<1*	*<600*	*<100*	*<300*	*<60*	*<300*
Number of sites not meeting target range		0/23	0/23	0/23	0/23	0/23	0/23	0/23
TFMS first tier trigger (0.6 mg/kg)*			*3/23*					

* Three sites (GW005, GW105 and GW115) had cadmium values exceeding the Tiered Fertiliser Management System (TFMS) first tier trigger value (0.6 mg/kg) as per the New Zealand Cadmium Management Strategy.

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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 (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).

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.

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