greater WELLINGTON
REGIONAL COUNCIL
Te Pane Matua Taiao

Soil Quality State of the Environment monitoring programme

Annual Data Report 2017/18

Dougall Gordon
Environmental Science Department

For more information, contact the Greater Wellington Regional Council:

Wellington
PO Box 11646

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

Masterton
PO Box 41

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

GW/ESCI-T-18/146

June 2019

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

Report prepared by:	D A Gordon	Senior Scientist	
Report reviewed by:	P Crisp	Team Leader	
Report approved for release by:	L Baker	Manager, Environmental Science	Date: June 2019

The report may be cited as:

Gordon D.A. 2018. Soil Quality State of Environment monitoring programme: Annual data report 2017/18. Greater Wellington Regional Council, Publication No. GW/ESCI-T-18/146, Wellington.

Contents

1. Introduction 1

2. Overview of SoE monitoring programme 2
2.1 Monitoring objectives 2
2.2 Monitoring network 3
2.3 Monitoring Methods 8
2.4 Monitoring variables 8
2.5 Soil quality targets and guidelines 8
2.6 Trace element targets, draft eco-soil guidelines and trigger values 9

3. Results 10
3.1 Regional Soil Monitoring Results 10
3.2 Soil results for the Ruamahanga Whaitua 15
3.3 Soil results for the Kapiti Whaitua 17
3.4 Soils results for the Porirua and Eastern Wairarapa Whaitua 19

Acknowledgements 22

References 22

Appendix 1: Soil Quality Indicators 25
1.1 Soil Physical Properties 25
1.2 Soil chemical properties 25

Appendix 2: Analytical methods 28

Appendix 3: Soil quality targets 29

Appendix 4 Soil Monitoring Results 2018 33

1. Introduction

Greater Wellington's Soil Quality State of the Environment (SoE) monitoring programme consists of annual monitoring frequency at sites on a range of soils type across the region under different land uses. The SOE programme has a rolling rotation of monitoring sites under different landuses.

This report summarises the results of soil quality sampling undertaken in 2018 at 19 sites under either exotic forestry or horticulture land use. The soil quality monitoring results are then compared with current soil guidelines as developed by the Regional Council Land Monitoring Forum in 2009 to provide a "state" assessment of soil quality. Trend analysis is considered in 5 year reporting cycle.

2. Overview of SoE monitoring programme

Greater Wellington Regional Council (GWRC) participated in the national soil quality programme known as the “500 Soils Project” conducted by Landcare Research in 2000 (Sparling & Schipper 2004). The objective of this “Project” was to measure and assess soil quality at 500 sites throughout New Zealand to provide a nationally consistent dataset and to provide local and central government with an understanding of soil quality in New Zealand.

At the conclusion of the 500 soils Project, GWRC implemented a soil quality monitoring programme as part of GW’s State of the Environment programme to meet the monitoring requirements of section 35 of the Resource Management Act (1991) and to provide information to measure Regional Plan policy effectiveness.

A standard set of sampling methods, to measure physical, chemical and biological soil properties were used and a set of indicators developed to assess soil quality during the 500 Soils Project. These sampling methods and indicators were adopted by the Regional Council Land Monitoring Forum in 2009 for State of the Environment Reporting purposes and are used for GWRC’s soil quality monitoring programme.

2.1 Monitoring objectives

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

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

2.2 Monitoring network

GWRC's soil quality monitoring programme consists of approximately 100 monitoring sites on a range of 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, dry stock, horticulture and exotic forestry sites are sampled every 5-7 years, while indigenous vegetation sites are sampled every 10 years.

Nineteen sites were sampled during June 2018 across the region (Figure 2.1) of which thirty-two % were originally in forestry land use and sixty-eight % were horticulture land use sites(Figure 2.2). Thirty-seven % of the sites have undergone a change in land use since the soil monitoring programme commenced in 2001. No change in land use occurred at exotic forestry sites, but land use for horticulture sampling sites had changed to dry stock, market gardening, dairying, lifestyle and domestic gardens (Figure 2.3).

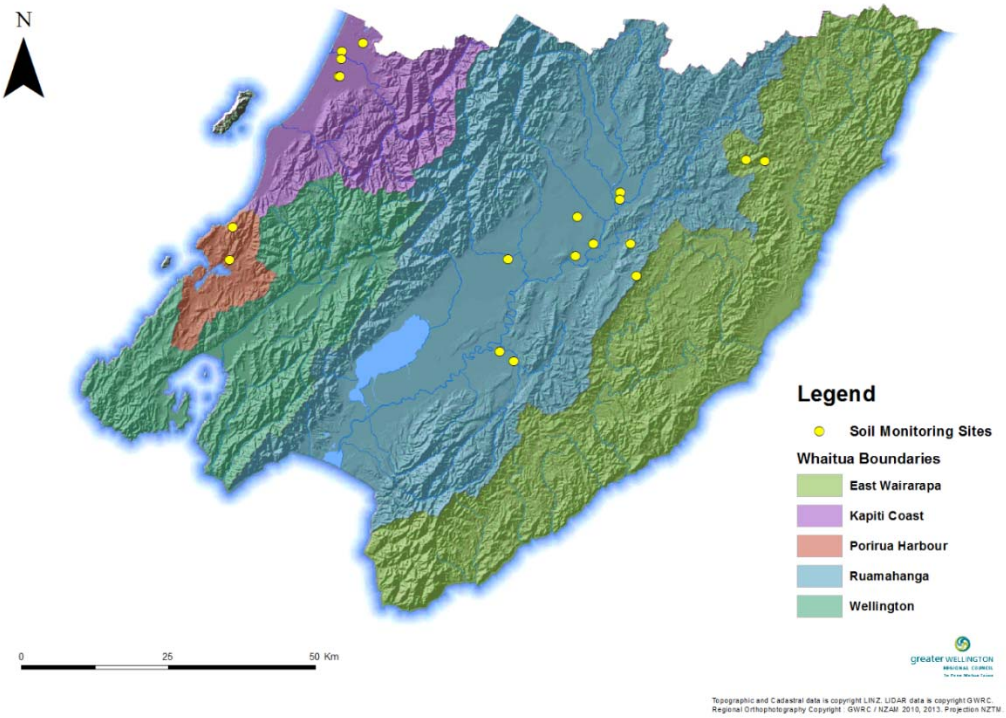

Figure 2.1: Soil quality monitoring sites sampled in 2018

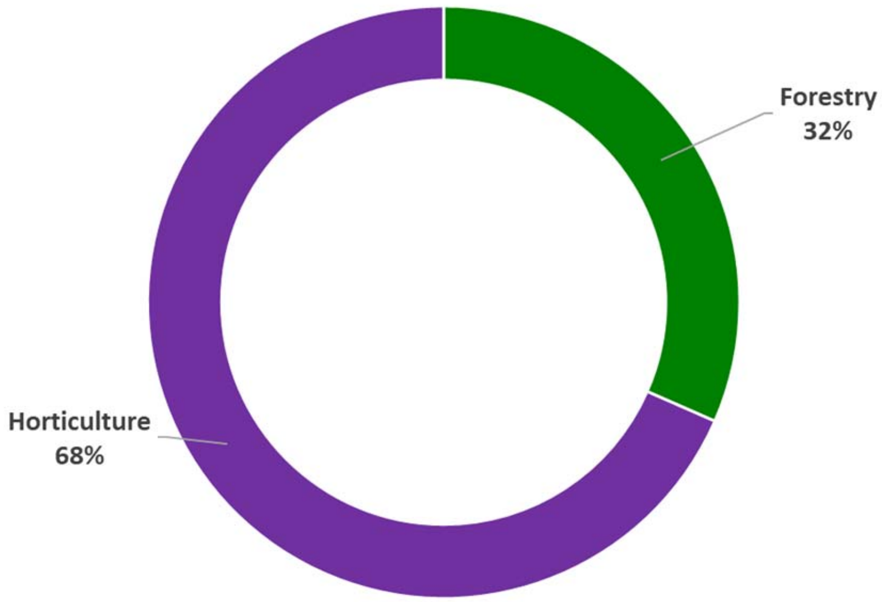

Figure 2.2: Proportion of forestry and horticulture land use at soil monitoring sites at the commencement of soil monitoring programme in 2001

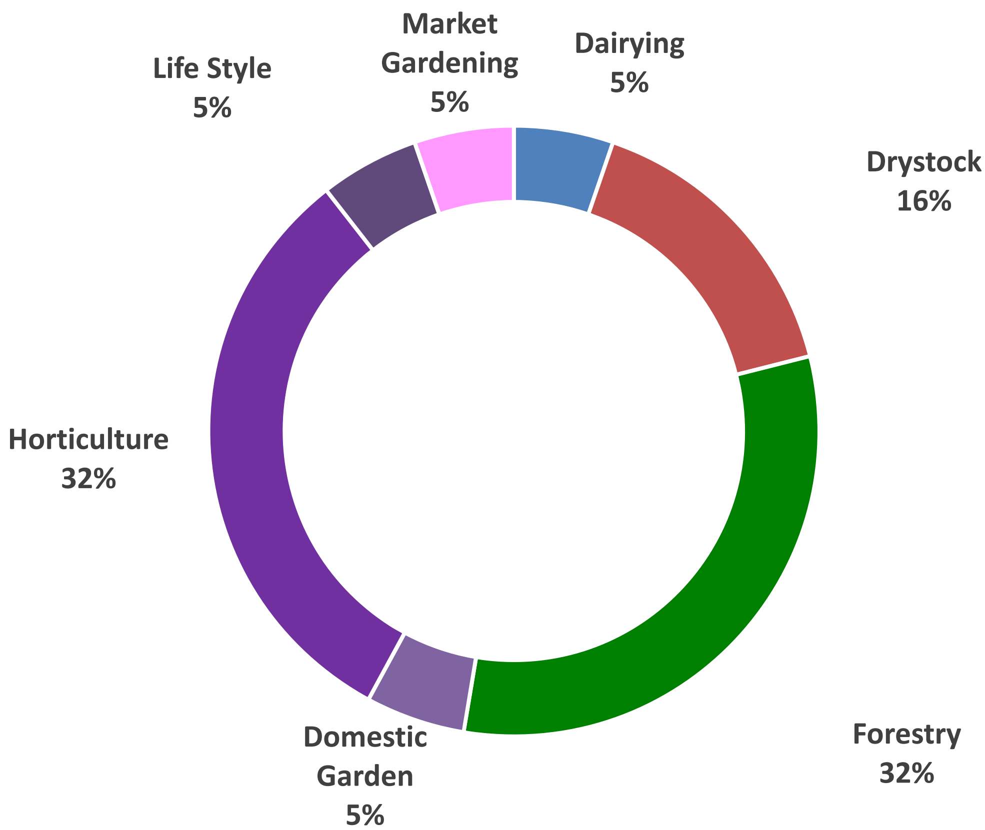

Figure 2.3: Land use types at soil monitoring sites in 2018

Spatially, there are ten sites in the Ruamahanga, five on the Kapiti Coast, two in Porirua, and two in the Eastern Wairarapa Whaitua (catchment management areas), (Figure 2.1).

A range of soil orders were sampled for the 2018 monitoring sites. Details of the soil order, group, subgroup and soil type for each site are presented in Table 2.1. The soil classification system used is the New Zealand Soil Classification (Hewitt 2010). This 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). The new S-Map soil classification that has been developed by Landcare Research has been included in Table 2.2 for the relevant monitoring sites where S-Map coverage is available. For more information about S-Map, refer to https://smap.landcareresearch.co.nz .

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, while Recent Soils have minimal soil profile development (McLaren & Cameron 1996; Hewitt 2010).

Table 2.1: Soil monitoring site location, historical land use and current land use, type and vegetation or farming system

Site	Whaitua (Catchment)	District	Historical Land use	Land use 2018	Land use Type 2018	Land vegetation or farming system 2018
GW001	Kapiti	Kapiti	Horticulture	Horticulture	Organic Orchard	Plums, Avocadoes, Berries
GW025	Ruamahanga	Carterton	Horticulture	Drystock	Lifestyle Block	Sheep grazing
GW028	Kapiti	Kapiti	Horticulture	Pasture	Lifestyle Block	Mowed paddock
GW035	Ruamahanga	South Wairarapa	Horticulture	Horticulture	Viticulture	Grapes - Vineyard
GW041	Ruamahanga	Carterton	Horticulture	Horticulture	Viticulture	Grapes - Vineyard
GW047	Kapiti	Kapiti	Horticulture	Horticulture	Fruit Growing	Strawberry Field - Tilled
GW053	Porirua	Porirua	Forestry	Forestry	Exotic Forestry	*Pinus radiata* 5 yrs post-harvest. Gorse understory
GW055	Porirua	Porirua	Forestry	Forestry	Exotic Forestry	*Pinus radiata* - mid maturity
GW062	Ruamahanga	Carterton	Forestry	Forestry	Exotic Forestry	*Pinus radiata* - plantation nearing maturity
GW064	Ruamahanga	Carterton	Forestry	Forestry	Exotic Forestry	*Pinus radiata* - plantation nearing maturity
GW067	East Wairarapa	Masterton	Forestry	Forestry	Exotic Forestry	*Pinus radiata* - plantation nearing maturity
GW069	East Wairarapa	Masterton	Forestry	Forestry	Exotic Forestry	*Pinus radiata* - plantation 2-3 yrs post-harvest
GW073	Ruamahanga	Masterton	Horticulture	Drystock	Lifestyle	New pasture - Low intensity free range pigs
GW074	Ruamahanga	Masterton	Horticulture	Dairying	Dairying	Long red clover & ryegrass pasture
GW077	Ruamahanga	Carterton	Horticulture	Horticulture	Organic Viticulture	Grapes - Organic vineyard-Certified Biogrow
GW081	Ruamahanga	South Wairarapa	Horticulture	Drystock	Sheep and Beef	Long Red clover & ryegrass pasture
GW083	Ruamahanga	South Wairarapa	Horticulture	Horticulture	Viticulture	Grapes - Vineyard
GW089	Kapiti	Kapiti	Horticulture	Horticulture	Orchard & Free Range Poultry & Lifestyle block	Fruit trees & free range chickens
GW091	Kapiti	Kapiti	Horticulture	Market Gardening	Vegetable Growing	Rhubarb Crop

Table 2.2: Soil order, subgroup, name and soil type for soil monitoring sites based on the New Zealand Soil Classification and S-Map

Site	NZSC Soil Order	NZSC Soil Subgroup	NZSC Soil Type	S-Map Soil Classification	S-Map Soil Family Name & Type	S-Map Soil Type
GW001	Brown	Typic Orthic Brown	Ashurst stony silt loam	Typic Orthic Allophanic	Ashurst very stony silt loam	Very stony silt loam
GW025	Gley	Typic Recent Gley	Ahikouka silt loam	Argillic-frangic Perched Gleyed Pallic	Mairaka moderately deep silty loam over clay	Moderately deep silty loam over clay
GW028	Recent	Acidic-weathered Fluvial Recent	Manawatu shallow silt loam	Fluvial Raw Soils	Rangitikei Shallow Loam	Shallow Loam
GW035	Pallic	Typic Immature Pallic	Martinborough silt loam	Typic Immature Pallic	Barhill moderately deep silt loam	Moderately deep silt loam
GW041	Pallic	Typic Immature Pallic	Tauherenikau gravelly sandy loam	Pallic Firm Brown	Lismore very stony silt loam	Very stony silt loam
GW047	Gley	Acidic Orthic Gley	Rahui silt loam	Typic Orthic Allophanic	Levin deep silty loam	Deep silty loam
GW053	Brown	Typic Orthic Brown	Makara stony loam	Typic Orthic Allophanic	Tengawai silty loam	Silty loam
GW055	Brown	Typic Firm Brown	Korokoro silt loam	Typic Firm Brown	Asheridge loam	Loam
GW062	Brown	Typic Firm Brown	Pirinoa silt loam	not available	not available	not available
GW064	Melanic	Weathered Rendzic Melanic	Kourarau clay	not available	not available	not available
GW067	Recent	Typic Orthic Recent	Whareama silt loam	not available	not available	not available
GW069	Recent	Typic Orthic Recent	Taihape silt loam	not available	not available	not available
GW073	Recent	Weathered Fluvial Recent	Greytown silt loam	Mottled-weathered Fluvial Recent	Waimakariri moderately deep silty loam	Moderately deep silty loam
GW074	Gley	Typic Recent Gley	Ahikouka silt loam	Typic Immature Pallic	Templeton deep silty loam	Deep silty loam
GW077	Pallic	Mottled Argillic Pallic	Kokotau silt loam	Mottled Argillic Pallic	Pahua moderately deep silty loam over clay	Moderately deep silty loam over clay
GW081	Recent	Weathered Fluvial Recent	Greytown silt loam	Mottled-weathered Fluvial Recent	Kaiapoi deep silty loam	Deep silty loam
GW083	Brown	Pallic Orthic Brown	Martinborough stony silt loam	Typic Immature Pallic	Barhill moderately deep silt loam	Moderately deep silt loam
GW089	Brown	Typic Orthic Brown	Ashurst stony silt loam	Typic Acid Brown Soils	Ashhurst very stony silt loam	Very stony silt loam
GW091	Gley	Typic Orthic Gley	Kairanga silt loam	Acidic Recent Gley Soil	Paroa deep silty loam	Deep silty loam

2.3 Monitoring Methods

At each site, a 50 m transect was used to collect 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 collected along the 50m transect at intervals of 15, 30 and 45 m. The intact cores were collected by pressing steel liners (10 cm in diameter and 7.5 cm in depth) into the top 10 cm of soil and sent to the soil physics laboratory. 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).

2.4 Monitoring variables

Soil properties used as indicators of soil quality include bulk density, macroporosity, total carbon, total nitrogen, anaerobic mineralisable nitrogen, pH, Olsen P and heavy metal trace elements. These indicators are grouped into four general areas of soil quality: physical condition, organic resources, fertility and trace elements which provide an overall assessment of soil health.

A summary of the soil quality indicators is described in Table 2.3. The full 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 available in the report of the Land Monitoring Forum (2009).

Table 2.3: 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

2.5 Soil quality targets and guidelines

Soil quality indicators are used to assess how land use and management practices influence soil for plant growth and to assess potential risks to the environment, in particular water quality. To help improve interpretation of soil quality indicators, targets were developed and are now routinely used by regional councils (Hill & Sparling 2009). This provides a consistent reporting approach for the sector. Target ranges for the assessment of soil quality span from; very low, optimal, to very high for the main soil orders for each different land use (Hill & Sparling 2009). These interpretative ranges are presented in Appendix 3.

For this report, the target range for selected indicators by Hill and Sparling (2009) used the recommended "by exception" approach. Target ranges for soil orders, rather than land use are used to 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 by Taylor (2011a) and Mackay et al. (2013).

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

Draft eco-soil guideline values (Eco-SGVs) have recently been developed to protect soil and terrestrial biota; soil microbes, invertebrates, plants, wildlife and livestock (Cavanagh 2016). Eco-SGVs provide a useful means of assessing potential environmental impact which has not be available previously. The draft Eco-SGVs are presented in Appendix 3. For this report, 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 trace element results are also compared to the soil targets 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 (e.g., biosolids application), the values are generally transferable to other activities that share similar hazardous substances (MAF 2008). The biosolids guideline values for selected trace elements are presented in Appendix 3. The Health and Environmental Guidelines for Selected Timber Treatment Chemicals (MFE 1997), for example, can be used for assessing the concentrations of specific trace elements.

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

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

3. Results

3.1 Regional Soil Monitoring Results

Physical and chemical soil quality indicator results for each site are presented in Table 3.1. Mean values for the predominant land uses sampled for all 2018 monitoring sites are shown in Table 3.2. Raw soil quality monitoring results are presented in Appendix 4.

Olsen-P is well-recognised indicator of soil fertility and is increasingly being used as a soil quality indicator of risk to waterways (McDowell et al. 2004). Average phosphorus levels as measured by Olsen - P indicator are elevated across the region with highest levels occurring in market gardening and horticulture land uses. The regional average Olsen - P levels exceed the maximum target range of 40 mg/kg for those land uses on sedimentary soils at the market garden (80 mg/kg) and horticulture (78 mg/kg) land use sites, (Table 3.2).

Across the Greater Wellington region, 42% of sites met all soil indicators target ranges for soil type and land use (Table 3.3). Fifty-eight % had one or two indicators exceeding the target range for soil and land use type, with 32% of sites having two indicators exceeding the soil and land use target range. The most frequent indicator that was outside the target range is Olsen P with 40% of sites with Olsen P over the maximum target range. Horticulture land use had the highest level of exceedance of 100 to 269 % above the maximum target range of 40 mg/kg. One pasture land use monitoring site had Olsen P levels (10 mg/kg) below the recommended target (20 mg/kg). This level may limit production at this site.

Phosphorus is commonly strongly bound to soils. Soil erosion causing sediment to reach waterways often carries sediment bound phosphorus, which may result in accumulation in waterways enabling nuisance algal growth and detrimental changes to aquatic ecology. The high levels of phosphorus found at some sites across the region may have implications for localised water quality unless appropriate land management practices are in place.

The second most frequent indicator that was outside the target range is macroporosity which is an indicator of soil compaction. Thirty-seven % of all sites had soil macroporosity levels below the target range, with 43 % of horticulture land use sites having macroporosity levels below the target range of 10 (%v/v). The macroporosity ranged from 16% to 64 % below the target range of 10 (%v/v).

The low soil macroporosity levels may have deleterious effect on soil quality including reductions in soil drainage, soil air and soil biology which can impact on the productive capacity of the soil. The causes of low soil microporosity include; animal treading, heavy machinery tracking in wet soil conditions on horticulture orchards and cultivated land and some forest harvesting management practices (Vogeler et al. 2006; Drewry et al. 2008).

Trace element metal results are presented in Table 3.4. All soil trace metal results across the region are below the draft eco-soil guideline values that have been developed to protect soil and terrestrial biota (Cavanagh 2016). One site (GW025) has arsenic levels of 18.9 mg/kg, which are approaching the eco-soil guideline value and NZWW bio-solid guideline of 20 mg/kg.

All sites also have cadmium concentrations below the Tier 1 of the tiered fertiliser management strategy range of >0.6 to 1.0 mg/kg. Three sites had cadmium levels approaching the lower end of the Tier 1 range of 0.6 mg/kg (Table 3.4). These slightly elevated cadmium levels occurred at forestry and horticulture sites.

Table 3.1: Regional soil quality monitoring results for each sites. Values highlighted in red area exceed the target range and values highlighted in brown are below the target range.

Sample Name	Whaitua	Landuse 2018	NZSC Soil Order	pH	Organic C% (%)	Total N (%)	Anaerobic Mineralisable-N (mg/kg)	Olsen P (mg/Kg)	Bulk Density (M/m3)	Macro Porosity (%, v/v)	Trace Metal Range	No., of Indicators & trace metals outside range
GW001	Kapiti	Horticulture	Brown	6.0	8.51	0.76	150	96	0.76	13.7	0	1
GW025	Ruamahanga	Drystock	Recent	5.5	4.64	0.44	101	10	1.00	10.9	0	1
GW028	Kapiti	Pasture	Recent	6.1	4.36	0.39	78	51	1.09	9.0	0	2
GW035	Ruamahanga	Horticulture	Pallic	5.9	5.85	0.43	72	25	1.04	12.6	0	0
GW041	Ruamahanga	Horticulture	Pallic	6.1	7.50	0.65	116	32	0.78	21.8	0	0
GW047	Kapiti	Horticulture	Gley	6.2	2.4	0.24	47	140	1.18	13.6	0	2
GW053	Porirua	Forestry	Brown	4.5	6.03	0.33	52	6	0.95	29.1	0	0
GW055	Porirua	Forestry	Brown	4.6	7.72	0.46	30	24	0.85	22.6	0	0
GW062	Ruamahanga	Forestry	Brown	5.2	4.72	0.35	56	7	0.96	22.8	0	0
GW064	Ruamahanga	Forestry	Melanic	6.2	5.07	0.42	70	25	1.02	14.3	0	0
GW067	East Wairarapa	Forestry	Recent	4.6	5.59	0.37	50	88	1.00	10.6	0	1
GW069	East Wairarapa	Forestry	Recent	5.6	3.45	0.21	52	13	1.00	11.0	0	0
GW073	Ruamahanga	Drystock	Recent	6.1	3.57	0.33	105	33	1.16	3.6	0	1
GW074	Ruamahanga	Dairying	Gley	5.5	2.54	0.25	55	21	1.29	12.7	0	0
GW077	Ruamahanga	Horticulture	Pallic	6.4	4.31	0.40	102	26	1.08	7.5	0	1
GW081	Ruamahanga	Drystock	Recent	6.1	2.76	0.26	83	51	1.21	8.4	0	2
GW083	Ruamahanga	Horticulture	Brown	6.5	5.66	0.49	105	80	1.23	6.9	0	2
GW089	Kapiti	Horticulture	Brown	6.3	7.90	0.67	150	148	0.97	8.1	0	2
GW091	Kapiti	Market Gardening	Gley	6.1	4.07	0.35	57	80	1.18	7.3	0	2
Indicator Target Ranges												
Pallic and Recent Soils					2.0 to 12				0.4 to 1.4			
Other Soils					2.5 to 12				0.7 to 1.4			
Pasture				5.0 to 7.6		0.25 to 0.7	>50					
Forestry				3.5 to 7.6		0.10 to 0.7	>20					
Horticulture on all soils on all soils except organic				5.0 to 7.6		Not set	>20					
Market gardening on all soils except organic				5.0 to 7.6		Not set	>20					
Forestry - All soils								5 to 30				
Pasture, horticulture and cropping on sedimentary soils								20 to 40				
Forestry landuse										10 to 30		
Pasture, horticulture and cropping landuse										10 to 30		
Number of sites EXCEEDING target range limits				0	1	0	0	9	0	7	0	
Number of sites within target range limits				19	18	19	19	10	19	12	0	
% of sites EXCEEDING target range limits				0%	5%	0%	0%	47%	0%	37%	0%	

Table 3.2: Regional average of chemical and physical soil indicators for each land use

Land use 2018	Number of Sites	pH	Organic C% (%)	Total N (%)	Anaerobic Mineralisable-N (mg/kg)	Olsen P (mg/Kg)	Bulk Density (M/m3)	Macro Porosity (%, v/v)
Horticulture	7	6.18	6.02	0.52	106	78	1.01	12.0
Forestry	6	5.11	5.43	0.36	52	27	0.96	18.4
Pasture - Dairy & Drystock	5	5.85	3.57	0.33	84	33	1.15	8.9
Market Gardening	1	6.13	4.07	0.35	57	80	1.18	7.3

Table 3.3: Number of sites with indicators exceeding the target range for the region

Number of indicators and trace metals elements outside target range	Number of sites in the Region outside target range	Percentage of sites in the region
0	8	42
1	5	26
2	6	32

Table 3.4: Regional trace metal element results (total recoverable) monitoring results for each site. Values are colour coded according to level range relative to guideline values

Sample Name	Whaitua	Landuse 2018	NZSC Soil Order	Arsenic mg/Kg	Cadmium (mg/Kg)	Chromium (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Nickel (mg/Kg)	Zinc (mg/Kg)
GW001	Kapiti	Horticulture	Brown	4.6	0.51	13	93	10	4.8	47
GW025	Ruamahanga	Drystock	Gley	18.9	0.13	12	15	11	7.4	60
GW028	Kapiti	Pasture	Recent	6.3	0.28	13	29	19	14.2	74
GW035	Ruamahanga	Horticulture	Pallic	4.4	0.17	13	14	12	7.3	53
GW041	Ruamahanga	Horticulture	Pallic	3.3	0.24	17	24	10	12.4	56
GW047	Kapiti	Horticulture	Gley	3.2	0.26	12	15	9	9.7	62
GW053	Porirua	Forestry	Brown	1.3	0.04	6	3	7	4.2	22
GW055	Porirua	Forestry	Brown	2.2	0.12	6	4	7	2.5	14.6
GW062	Ruamahanga	Forestry	Brown	2.7	0.08	14	5	9	11	39
GW064	Ruamahanga	Forestry	Melanic	7.4	0.58	18	8	17	9.5	37
GW067	East Wairarapa	Forestry	Recent	6	0.09	8	8	10	7.5	47
GW069	East Wairarapa	Forestry	Recent	6.4	0.05	11	6	10	7.2	35
GW073	Ruamahanga	Drystock	Recent	4.9	0.18	18	13	14	14.3	70
GW074	Ruamahanga	Dairying	Gley	4.5	0.17	21	12	12	15.8	58
GW077	Ruamahanga	Horticulture	Pallic	3.7	0.15	12	23	9	7.4	55
GW081	Ruamahanga	Drystock	Recent	10.1	0.16	20	65	30	18.1	100
GW083	Ruamahanga	Horticulture	Brown	4.2	0.16	12	8	16	6.1	56
GW089	Kapiti	Horticulture	Brown	7	0.50	11	65	10	4.9	57
GW091	Kapiti	Market Gardening	Gley	6.9	0.31	16	19	28	13	75
Target range - Draft ECO-SGV agricultural land (Brown) guideline				<20	<1.5	<300	<150	<530		<190
Target Range - Draft ECO-SGV agricultural land (Recent) guideline				<20	<1.5	<300	<130	<530		<130
Number of sites below maxumum guidelines limit				19	19	19	19	19		19
% of sites below guideline limit				100%	100%	100%	100%	100%		100%
TFMS Tier 0 Cadmium target					0.0 to 0.6					
TFMS Tier 1 Cadmium target					>0.60 to 1.0					
Number of sites within Teir 0 Target Range					19					
% sites within Tier 0 Target Range					100%					

3.2 Soil results for the Ruamahanga Whaitua

The Ruamahanga Whaitua had the highest number of monitoring sites but also has the largest physical area of the Greater Wellington Region. Physical and chemical soil quality indicator results for each site are presented in Table 3.6.

Fifty % of sites in the Ruamahanga Whaitua met all soil indicator target ranges for soil type and land use and 40 % had one indicator exceeding the target range, with 10% of sites having two indicators exceeding the target guideline range (Table 3.5). The most frequent indicator that was outside the target range is macroporosity with 40 % of sites below the target range of 10 (%v/v). This occurred in pasture and horticulture land uses. The low soil macroporosity levels may have deleterious effect on soil quality including soil drainage, soil air andsoil biology which can impact on the productive capacity of the soil.

The second most frequent indicator exceeding target range is Olsen-P, with 30% of sites exceeding the target range. Most sites were exceeding the maximum target limits of 40 mg/kg with one site (GW025) below the minimum target of 20 mg/kg.

Table 3.5: Number of sites with indicators exceeding the target range for the Rumahanga Whaitua

Number of indicators and trace metals elements outside target range	Number of sites in the Region outside target range	Percentage of sites in the Whaitua
0	5	50
1	4	40
2	1	10

Table 3.6: Soil quality monitoring results for each site for the Ruamahanga Whaitua. Values highlighted in red area exceed the target range and values highlighted in brown are below the target range

Sample Name	Whaitua	Landuse 2018	NZSC Soil Order	pH	Organic C (%)	Total N (%)	Anaerobic Mineralisable-N (mg/kg)	Olsen P (mg/Kg)	Bulk Desnsity (M/m3)	Macro Porosity (%, v/v)	Trace Metal Range	No., of Indicators & trace metals outside range
GW025	Ruamahanga	Drystock	Gley	5.51	4.64	0.44	101	10	1.00	10.9	0	1
GW035	Ruamahanga	Horticulture	Pallic	5.85	5.85	0.43	72	25	1.04	12.6	0	0
GW041	Ruamahanga	Horticulture	Pallic	6.14	7.50	0.65	116	32	0.78	21.8	0	0
GW062	Ruamahanga	Forestry	Brown	5.16	4.72	0.35	56	7	0.96	22.8	0	0
GW064	Ruamahanga	Forestry	Melanic	6.22	5.07	0.42	70	25	1.02	14.3	0	0
GW073	Ruamahanga	Drystock	Recent	6.06	3.57	0.33	105	33	1.16	3.6	0	1
GW074	Ruamahanga	Dairying	Gley	5.53	2.54	0.25	55	21	1.29	12.7	0	0
GW077	Ruamahanga	Horticulture	Pallic	6.35	4.31	0.40	102	26	1.08	7.5	0	1
GW081	Ruamahanga	Drystock	Recent	6.10	2.76	0.26	83	51	1.21	8.4	0	2
GW083	Ruamahanga	Horticulture	Brown	6.48	5.66	0.49	105	80	1.23	6.9	0	2
Indicator Target Ranges												
Pallic and Recent Soils					2.0 to 12				0.4 to 1.4			
Other Soils					2.5 to 12				0.7 to 1.4			
Pasture				5.0 to 7.6		0.25 to 0.70	>50					
Forestry				3.5 to 7.6		0.10 to 0.70	>20					
Horticulture on all soils on all soils except organic				5.0 to 7.6		Not set	>20					
Market gardening on all soils except organic				5.0 to 7.6		Not set	>20					
Forestry - All soils								5 to 30				
Pasture, horticulture and cropping on sedimentary soils								20 to 40				
Forestry landuse										10 to 30		
Pasture, horticulture and cropping landuse										10 to 30		
Number of sites EXCEEDING target range limits				0	0	0	0	3	0	4		
Number of sites within target range limits				10	10	10	10	8	10	6	10	
% of sites EXEEDING target range limits				0%	0%	0%	0%	30%	0%	40%	0%	

3.3 Soil results for the Kapiti Whaitua

The Kapti Whaitua has 26 % of the monitoring sites and the highest proportion of horticulture monitoring sites. There are currently no forestry sites monitored in the Kapiti Whaitua. Physical and chemical soil quality indicator results for each site are presented in Table 3.8.

All sites in Kapiti Whaitua had indicators exceeding the target range. Sixty% of sites had two indicators exceeding the target guideline range (Table 3.7). The most frequent indicator that was outside the target range was Olsen-P with 80% of sites above the target range of 40 mg/kg for pasture and horticulture land uses. Olsen – P levels range from 100 to 270% above the maximum target range. The high phosphorus levels may have implications for water quality unless appropriate land management practices are put in place.

Table 3.7: Number of sites with indicators exceeding the target range for the Kapiti Whaitua

Number of indicators and trace metals elements outside target range	Number of sites in the Region outside target range	Percentage of sites in the Whaitua
0	0	0
1	2	40
2	2	60

The second most frequent indicator that was exceeding the target range is macroporosity. Sixty % of sites have soil macroporosity levels below the target range of 10 (%v/v). These were in pasture, horticulture and market garden land uses. The macroporosity ranged from 10% to 37 % below the target range. The low soil macroporosity levels may have deleterious effect on soil quality including reducing soil drainage, soil air and soil biology which can impact on the productive capacity of the soil.

Table 3.8: Soil quality monitoring results for each sites for the Ruamahanga Whaitua. Values highlighted in red area exceed the target range and values highlighted in brown are below the target range

Sample Name	Whaitua	Landuse 2018	NZSC Soil Order	pH	Organic C% (%)	Total N (%)	Anaerobic Mineralisable-N (mg/kg)	Olsen P (mg/Kg)	Bulk Density (M/m3)	Macro Porosity (%, v/v)	Trace Metal Range	No., of Indicators & trace metals outside range
GW001	Kapiti	Horticulture	Brown	6.0	8.51	0.76	150	96	0.76	13.7	0	1
GW028	Kapiti	Pasture	Recent	6.1	4.36	0.39	78	51	1.09	9.0	0	1
GW047	Kapiti	Horticulture	Gley	6.2	2.40	0.24	47	140	1.18	13.6	0	2
GW089	Kapiti	Horticulture	Brown	6.3	7.90	0.67	150	148	0.97	8.1	0	2
GW091	Kapiti	Market Gardenin	Gley	6.1	4.07	0.35	57	80	1.18	7.3	0	2
Indicator Target Ranges												
Pallic and Recent Soils					2.0 to 12				0.4 to 1.4			
Other Soils					2.5 to 12				0.7 to 1.4			
Pasture				5.0 to 7.6		0.25 to 0.70	>50					
Forestry				3.5 to 7.6		0.10 to 0.70	>20					
Horticulture on all soils on all soils except organic				5.0 to 7.6		Not set	>20					
Market gardening on all soils except organic				5.0 to 7.6		Not set	>20					
Forestry - All soils								5 to 30				
Pasture, horticulture and cropping on sedimentary soils								20 to 40				
Forestry landuse										10 to 30		
Pasture, horticulture and cropping landuse										10 to 30		
Number of sites EXCEEDING target range limits				0	1	0	0	4	0	3	0	
Number of sites within target range limits				5	4	5	5	1	5	2	5	
% of sites EXCEEDING target range limits				0%	20%	0%	0%	80%	0%	60%	0%	

3.4 Soils results for the Porirua and Eastern Wairarapa Whaitua

Physical and chemical soil quality indicator results for sites in the Porirua and Eastern Wairarapa Whaitua are presented in Tables 3.9 and 3.10.

One of the two sites in the Eastern Wairarapa Whaitua had one indicator exceeding the target guidelines values. This site had Olsen-P levels 192 % above the maximum guidelines value of 30 mg/kg for forestry land use.

No sites exceeded all soil quality indicators for the Porirua Whaitua.

Table 3.9: Soil quality monitoring results for each sites for the Ruamahanga Whaitua. Values highlighted in red area exceed the target range and values highlighted in brown are below the target range

Sample Name	Whaitua	Landuse 2018	NZSC Soil Order	pH	Organic C% (%)	Total N (%)	Anaerobic Mineralisable-N (mg/kg)	Olsen P (mg/Kg)	Bulk Density (M/m3)	Macro Porosity (%, v/v)	Trace Metal Range	No., of Indicators & trace metals outside range
GW067	East Wairarapa	Forestry	Recent	4.6	5.59	0.37	50	88	1.00	10.6	0	1
GW069	East Wairarapa	Forestry	Recent	5.6	3.45	0.21	52	13	1.00	11.0	0	0
Indicator Target Ranges												
Pallic and Recent Soils					2.0 to 12				0.4 to 1.4			
Other Soils					2.5 to 12				0.7 to 1.4			
Pasture				5.0 to 7.6		0.25 to 0.70	>50					
Forestry				3.5 to 7.6		0.10 to 0.70	>20					
Horticulture on all soils on all soils except organic				5.0 to 7.6		Not set	>20					
Market gardening on all soils except organic				5.0 to 7.6		Not set	>20					
Forestry - All soils								5 to 30				
Pasture, horticulture and cropping on sedimentary soils								20 to 40				
Forestry landuse										10 to 30		
Pasture, horticulture and cropping landuse										10 to 30		
Number of sites EXCEEDING target range limits				0	0	0	0	1	0	0	0	
Number of sites within target range limits				2	2	2	2	1	2	2	2	
% of sites EXCEEDING target range limits				0%	0%	0%	0%	100%	0%	0%	0%	

Table 3.10: Soil quality monitoring results for each sites for the Ruamahanga Whaitua. Values highlighted in red area exceed the target range and values highlighted in brown are below the target range

Sample Name	Whaitua	Landuse 2018	NZSC Soil Order	pH	Organic C% (%)	Total N (%)	Anaerobic Mineralisable-N (mg/kg)	Olsen P (mg/Kg)	Bulk Density (M/m3)	Macro Porosity (%, v/v)	Trace Metal Range	No., of Indicators & trace metals outside range
GW053	Porirua	Forestry	Brown	4.5	6.03	0.33	52	6	0.95	29.1	0	0
GW055	Porirua	Forestry	Brown	4.6	7.72	0.46	30	24	0.85	22.6	0	0
Indicator Target Ranges												
Pallic and Recent Soils					2.0 to 12				0.4 to 1.4			
Other Soils					2.5 to 12				0.7 to 1.4			
Pasture				5.0 to 7.6		0.25 to 0.70	>50					
Forestry				3.5 to 7.6		0.10 to 0.70	>20					
Horticulture on all soils on all soils except organic				5.0 to 7.6		Not set	>20					
Market gardening on all soils except organic				5.0 to 7.6		Not set	>20					
Forestry - All soils								5 to 30				
Pasture, horticulture and cropping on sedimentary soils								20 to 40				
Forestry landuse										10 to 30		
Pasture, horticulture and cropping landuse										10 to 30		
Number of sites EXCEEDING target range limits				0	0	0	0	0	0	0	0	
Number of sites within target range limits				2	2	2	2	2	2	2	2	
% of sites EXCEEDING target range limits				0%	0%	0%	0%	0%	0%	0%	0%	

Acknowledgements

Thanks to the farmers and landowners who provided information and access to their land for sampling. Thanks to John Drewry, David McQueen and Feline Drummond for assistance with sampling.

References

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Appendix 1: Soil Quality Indicators

Indicators used for soil quality assessment (adapted from Hill & Sparling 2009) and an explanation of the importance of the soil indicator properties are summarised in table A1.1. A full description of soil property indicators is described in section 1.1 and 1.2 below.

1.1 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).

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.

1.2 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). 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 (e.g., 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). Whilst, 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.

Trace element metals 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. Trace elements occur naturally, and the natural concentrations of most trace elements can vary greatly depending on geologic parent material. Trace element metals 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 A1.1: 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 A2.1). Trace element analyses were undertaken at Hill Laboratories in Hamilton (Table A2.1). Where necessary, samples were stored at 4°C until analysis.

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

Olsen P measurements analysed at Landcare Research were undertaken using a gravimetric (weight) method to 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 measurement are based on a volumetric method. Further information and explanation is available from Drewry et al. (2013; 2015).

Table A2.1: Soil Quality analytical methods

Indicator	Method
Bulk density	Measured on a sub-sampled core dried at 105°C.
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 2002.

Appendix 3: Soil quality targets

Soil quality indicator target ranges from Hill and Sparling (2009) are presented in tables A31- A3.10. 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 (Table A3.7).

Table A3.1: Bulk density target ranges (t/m^3 or Mg/m^3)

Soil Type	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

Table A3.2: Macroporosity target ranges (% v/v at -10 kPa)

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

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

Table A3.3: Total carbon target ranges (% w/w)

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

Table A3.4: Total nitrogen target ranges (% w/w)

Land use	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					

Table A3.5: Mineralisable nitrogen target ranges (mg/kg)

Land use	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.

Table A3.6: Soil pH target ranges

Soil Type	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 & horticulture on all soils except Organic	4	5	5.5	7.2	7.6	8.5
Cropping & 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					

Table A3.7: Olsen P target ranges (units not reported) from Taylor (2011a) and Mackay et al. (2013) but considered to be mg/kg

Land use	Soil Type	Suggested Olsen P targets	
		Minimum	Maximum
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

Table A3.8: Draft eco-soil guideline values for trace element concentrations in soil, from Cavanagh (2016). Values presented are for agricultural land use only.

Note: 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)

Table A3.9: 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

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

Table A3.10: 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

Appendix 4 Soil Monitoring Results 2018

A4.1: Soil Chemistry Manaaki Whenua Landcare Research

Client	Sample	Water	pH	Organic	Total	C/N	KCl-extractable		Anaerobic	Olsen	Olsen P	Phosphate	Exchangeable				CEC	Base
ID	No.	Content	(2:5 Water)	C	N	ratio	NO_3-N	NH_4-N	Mineralisable-N	P	volumetric	Retention	Ca	Mg	K	Na		Saturation
		(method 104(ii))	(method 106(i))	(method 114	(method 114	(calculation)*	(method 118)		(method 120)	(method 124	method 124 mod	(method 132)	(method 142)*				(method 144(i))	(calculation)*
		(% dry wt)		(%)	(%)		(mg/kg)		(mg/kg)	(mg/kg)	(mg/l)	(%)	(cmol(+)/kg)				(cmol(+)/kg)	(%)
						*					*		*	*	*	*		*
GW001	M17/7883	66	6.00	8.51	0.76	11	13	2	150	96	83	27	21.8	4.62	1.20	0.24	33.0	84
GW025	M17/7884	48	5.51	4.64	0.44	11	36	15	101	10	10	32	9.57	1.66	0.79	0.07	20.3	60
GW028	M17/7885	39	6.07	4.36	0.39	11	17	4	78	51	49	20	14.5	1.76	0.65	0.09	19.7	86
GW035	M17/7886	39	5.85	5.85	0.43	14	24	4	72	25	23	33	13.6	2.59	1.03	0.05	25.7	67
GW041	M17/7887	50	6.14	7.50	0.65	11	28	1	116	32	27	32	21.1	3.60	0.78	0.04	30.1	85
GW047	M17/7888	36	6.16	2.40	0.24	10	8	3	47	140	142	30	7.68	1.42	1.88	0.02	16.5	67
GW053	M17/7889	33	4.52	6.03	0.33	18	9	11	52	6	5	32	2.54	1.44	0.48	0.18	20.6	23
GW055	M17/7890	39	4.57	7.72	0.46	17	14	2	30	24	24	46	4.30	2.37	0.59	0.56	28.1	28
GW062	M17/7891	28	5.16	4.72	0.35	14	1	3	56	7	7	27	10.3	3.88	0.68	0.42	24.9	61
GW064	M17/7892	40	6.22	5.07	0.42	12	15	2	70	25	24	32	25.7	2.53	0.41	0.34	30.7	95
GW067	M17/7893	36	4.63	5.59	0.37	15	47	5	50	88	79	21	9.14	2.72	1.33	0.23	25.1	54
GW069	M17/7894	35	5.56	3.45	0.21	16	6	6	52	13	12	18	11.0	3.49	0.67	0.13	18.4	83
GW073	M17/7895	34	6.06	3.57	0.33	11	47	1	105	33	32	21	12.0	1.87	0.91	0.00	17.0	87
GW074	M17/7896	26	5.53	2.54	0.25	10	29	4	55	21	21	18	8.25	1.11	0.33	0.02	13.2	74
GW077	M17/7897	40	6.35	4.31	0.40	11	43	5	102	26	23	27	14.3	1.95	1.69	0.09	21.6	83
GW081	M17/7898	37	6.10	2.76	0.26	11	28	2	83	51	48	17	9.79	1.40	0.51	0.06	14.3	82
GW083	M17/7899	40	6.48	5.66	0.49	12	36	1	105	80	67	26	22.0	2.30	1.46	0.07	28.3	91
GW089	M17/7900	61	6.29	7.90	0.67	12	17	2	150	148	125	25	25.5	3.33	1.80	0.14	35.3	87
GW091	M17/7901	38	6.13	4.07	0.35	12	10	1	57	80	71	28	13.4	2.54	1.43	0.20	23.8	74

Table A4.2: Hills Laboratory Soil Chemistry

Site Name	Date Sampled	Sample Fraction Code	Analyte Name	Analyte Unit	Test Method Name	Result
GW001	7/06/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	4.6
GW001	7/06/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.51
GW001	7/06/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	13
GW001	7/06/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	93
GW001	7/06/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	14,700
GW001	7/06/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	9.6
GW001	7/06/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	310
GW001	7/06/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	4.8
GW001	7/06/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	1.02
GW001	7/06/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	47
GW001	7/06/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	310
GW025	16/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	18.9
GW025	16/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.127
GW025	16/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	11.8
GW025	16/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	14.6
GW025	16/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	14,000
GW025	16/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	11
GW025	16/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	1,160
GW025	16/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	7.4
GW025	16/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.5
GW025	16/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	60
GW025	16/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	174
GW028	7/06/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	6.3
GW028	7/06/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.28
GW028	7/06/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	13.1
GW028	7/06/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	29
GW028	7/06/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	23,000
GW028	7/06/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	19.2
GW028	7/06/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	460
GW028	7/06/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	14.2
GW028	7/06/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.88
GW028	7/06/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	74
GW028	7/06/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	450
GW035	15/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	4.4
GW035	15/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.167
GW035	15/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	12.5
GW035	15/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	14.4

Site Name	Date Sampled	Sample Fraction Code	Analyte Name	Analyte Unit	Test Method Name	Result
GW035	15/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	17,700
GW035	15/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	11.9
GW035	15/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	460
GW035	15/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	7.3
GW035	15/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.57
GW035	15/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	53
GW035	15/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	210
GW041	16/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	3.3
GW041	16/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.24
GW041	16/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	16.8
GW041	16/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	24
GW041	16/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	23,000
GW041	16/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	10.1
GW041	16/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	590
GW041	16/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	12.4
GW041	16/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.79
GW041	16/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	56
GW041	16/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	290
GW047	7/06/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	3.2
GW047	7/06/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.26
GW047	7/06/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	12.2
GW047	7/06/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	14.6
GW047	7/06/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	18,200
GW047	7/06/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	9.4
GW047	7/06/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	1070
GW047	7/06/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	9.7
GW047	7/06/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.93
GW047	7/06/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	62
GW047	7/06/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	310
GW053	1/06/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	1.3
GW053	1/06/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.036
GW053	1/06/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	6.4
GW053	1/06/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	3.4
GW053	1/06/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	10,200
GW053	1/06/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	6.5
GW053	1/06/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	300
GW053	1/06/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	4.2
GW053	1/06/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.31

Site Name	Date Sampled	Sample Fraction Code	Analyte Name	Analyte Unit	Test Method Name	Result
GW053	1/06/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	22
GW053	1/06/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	130
GW055	1/06/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	2.2
GW055	1/06/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.124
GW055	1/06/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	5.6
GW055	1/06/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	3.7
GW055	1/06/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	10,800
GW055	1/06/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	6.7
GW055	1/06/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	93
GW055	1/06/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	2.5
GW055	1/06/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.44
GW055	1/06/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	14.6
GW055	1/06/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	163
GW062	29/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	2.7
GW062	29/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.076
GW062	29/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	14.1
GW062	29/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	5.2
GW062	29/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	19,200
GW062	29/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	9.2
GW062	29/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	350
GW062	29/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	11
GW062	29/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.43
GW062	29/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	39
GW062	29/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	240
GW064	16/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	7.4
GW064	16/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.58
GW064	16/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	17.8
GW064	16/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	8
GW064	16/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	22,000
GW064	16/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	16.5
GW064	16/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	640
GW064	16/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	9.5
GW064	16/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.51
GW064	16/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	37
GW064	16/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	230
GW067	29/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	6
GW067	29/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.088
GW067	29/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	7.8

Site Name	Date Sampled	Sample Fraction Code	Analyte Name	Analyte Unit	Test Method Name	Result
GW067	29/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	7.6
GW067	29/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	14,000
GW067	29/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	9.5
GW067	29/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	580
GW067	29/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	7.5
GW067	29/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.49
GW067	29/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	47
GW067	29/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	168
GW069	17/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	6.4
GW069	17/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.049
GW069	17/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	11
GW069	17/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	5.9
GW069	17/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	16,700
GW069	17/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	9.9
GW069	17/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	230
GW069	17/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	7.2
GW069	17/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.65
GW069	17/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	35
GW069	17/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	200
GW073	10/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	4.9
GW073	10/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.182
GW073	10/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	18
GW073	10/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	12.6
GW073	10/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	22,000
GW073	10/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	14.3
GW073	10/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	500
GW073	10/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	14.3
GW073	10/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.65
GW073	10/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	70
GW073	10/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	340
GW074	16/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	4.5
GW074	16/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.167
GW074	16/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	21
GW074	16/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	12
GW074	16/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	24,000
GW074	16/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	12.2
GW074	16/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	480
GW074	16/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	15.8

Site Name	Date Sampled	Sample Fraction Code	Analyte Name	Analyte Unit	Test Method Name	Result
GW074	16/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.69
GW074	16/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	58
GW074	16/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	320
GW077	16/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	3.7
GW077	16/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.15
GW077	16/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	11.8
GW077	16/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	23
GW077	16/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	17,200
GW077	16/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	8.5
GW077	16/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	1,200
GW077	16/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	7.4
GW077	16/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.63
GW077	16/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	55
GW077	16/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	210
GW081	17/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	10.1
GW081	17/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.164
GW081	17/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	20
GW081	17/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	65
GW081	17/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	24,000
GW081	17/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	30
GW081	17/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	450
GW081	17/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	18.1
GW081	17/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.6
GW081	17/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	100
GW081	17/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	490
GW083	15/05/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	4.2
GW083	15/05/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.162
GW083	15/05/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	12
GW083	15/05/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	8.2
GW083	15/05/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	22,000
GW083	15/05/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	15.6
GW083	15/05/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	610
GW083	15/05/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	6.1
GW083	15/05/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	0.7
GW083	15/05/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	56
GW083	15/05/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	240
GW089	7/06/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	7
GW089	7/06/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.5

Site Name	Date Sampled	Sample Fraction Code	Analyte Name	Analyte Unit	Test Method Name	Result
GW089	7/06/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	11
GW089	7/06/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	65
GW089	7/06/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	15,000
GW089	7/06/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	9.5
GW089	7/06/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	420
GW089	7/06/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	4.9
GW089	7/06/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	1.17
GW089	7/06/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	57
GW089	7/06/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	380
GW091	7/06/2018	esDig	Total Recoverable Arsenic	mg/kg dry wt	Total Recoverable Arsenic	6.9
GW091	7/06/2018	esDig	Total Recoverable Cadmium	mg/kg dry wt	Total Recoverable Cadmium	0.31
GW091	7/06/2018	esDig	Total Recoverable Chromium	mg/kg dry wt	Total Recoverable Chromium	16.3
GW091	7/06/2018	esDig	Total Recoverable Copper	mg/kg dry wt	Total Recoverable Copper	19.1
GW091	7/06/2018	esDig	Total Recoverable Iron	mg/kg dry wt	Total Recoverable Iron	21,000
GW091	7/06/2018	esDig	Total Recoverable Lead	mg/kg dry wt	Total Recoverable Lead	28
GW091	7/06/2018	esDig	Total Recoverable Manganese	mg/kg dry wt	Total Recoverable Manganese	270
GW091	7/06/2018	esDig	Total Recoverable Nickel	mg/kg dry wt	Total Recoverable Nickel	13
GW091	7/06/2018	esDig	Total Recoverable Uranium	mg/kg dry wt	Total Recoverable Uranium	1.09
GW091	7/06/2018	esDig	Total Recoverable Zinc	mg/kg dry wt	Total Recoverable Zinc	75
GW091	7/06/2018	esF_AlkFusion	Fluoride	mg/kg dry wt	Total Fluoride in Solids	560