Soil quality and stability in the Wellington region

State and trends

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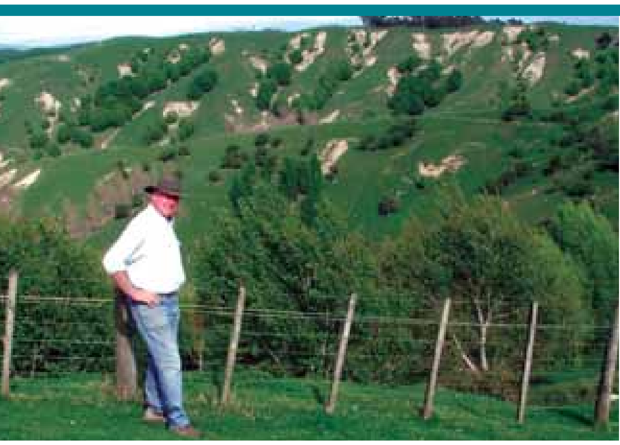

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Main cover photo: Market garden near Otaki

Executive summary

Greater Wellington monitors the quality of soils at over 100 sites under a range of land uses across the Wellington region, as well as the integrity – or stability – of soils in the region. Poor quality or unstable soils can reduce the land's productive capability on-site, and put pressure on the environment off-site, particularly if soil enters surface water bodies or nutrients in the soils leach into the underlying groundwater.

This report provides a comprehensive assessment of the results of State of the Environment (SoE) soil quality monitoring undertaken in the Wellington region between 2000 and 2010, including any trends in soil quality over this period. The report also summarises the results of regional soil stability surveys undertaken in 2002 and 2010.

Analysis of the most recent round of soil quality sampling results under each land use monitored indicates that the soils at most monitoring sites in the Wellington region are currently in a reasonable condition. However, some land uses, notably vegetable growing and dairy farming, are clearly impacting on soil quality, particularly in and around Otaki.

The results for many vegetable growing sites indicate intensive cultivation has reduced soil carbon to low levels, degraded soil structure and compacted soils, while continued fertiliser usage has resulted in very high levels of Olsen P in the soil. In combination, these soil conditions increase the risk of soil and nutrients entering ground and surface waters (particularly phosphorus), and potentially, negatively impact on production.

Dairy farm sites also had significant soil quality issues, primarily compaction due to low macroporosity. Very high concentrations of nitrogen and Olsen P were found in soil samples from some sites, and the highest concentrations of cadmium out of all the land uses were found at dairy farm sites. These issues are likely to have been caused by grazing animals on wet soils, high stocking rates and high inputs of nutrients from both animals and fertilisers (superphosphate). Compacted soils have a direct impact on pasture growth and overall production, while elevated concentrations of nutrients in the soil increase the risk of nutrients entering ground and surface waters.

While few statistically significant changes were found in the mean values of soil quality indicators at vegetable growing sites sampled on three occasions between 2000 and 2010, at dairy farm sites, there were significant increases in Olsen P, total nitrogen, anaerobic mineralisable nitrogen and total recoverable cadmium concentrations over the three sampling events. Macroporosity also increased significantly over time; although this is a positive or improving trend, overall, the values remain consistently low. Soil cadmium concentrations are not currently at levels of immediate concern but the increase in mean concentration across the three surveys suggests accumulation of cadmium in dairy farm soils needs to be monitored closely.

Of the other land use types monitored, drystock farm sites had similar issues to dairy farm sites, but to a lesser degree. Compaction was common, but both nitrogen and Olsen P concentrations were more variable; at some sites nutrient levels were too high and at others they were deficient. The impacts on soil quality at the horticulture and cropping sites were minimal (although sample sizes for these land uses are small) and the soil at the forestry sites showed no impacts from land use.

The results of regional soil stability surveys undertaken in 2002 and 2010 showed that the majority of the Wellington region’s soil is intact, and there has been a slight increase in stable and inactive land surfaces due to the re-vegetation of some former erosion scars. However, soil disturbance caused by land use activities increased by approximately 24,000 ha across the region since 2002, with land use activities such as farm and forest tracking, cultivation, spraying for pasture renewal and grazing pressure causing most of the disturbance. Soil conservation in the form of woody vegetation remains important for the region due to the susceptibility of erosion in the eastern Wairarapa hill country. Across the region, approximately 89,300 ha of land requires some form of protection against erosion. This indicates a significant amount of farmland still needs to be either allowed to regenerate, or be supplemented with soil conservation covers in the form of soil conservation pole plantings.

Contents

1. Introduction

Soils in the Wellington region support a wide range of land uses, including horticulture, viticulture, vegetable growing, cropping, dairy farming, drystock farming and forestry. Greater Wellington Regional Council (Greater Wellington) monitors the region's soils to assess the potential for these land uses to adversely affect soil health. Inappropriate land use practices, such as overstocking and over-cultivation, can result in a long-term reduction in soil quality. Poor soil quality can also produce lower agricultural yields, a less resilient soil and land ecosystem, and increase the risks of contamination of underlying groundwater and nearby surface water bodies.

Greater Wellington also monitors the integrity of the region's soils. As well as impacting on soil quality, land use practices can also impact on soil stability, intactness and disturbance. Unstable and disturbed land surfaces are prone to erosion processes which can lead to bare soil. This can reduce the land's productive capability on-site, and put pressure on the environment off-site, particularly if soil enters surface water bodies.

This report provides a comprehensive assessment of the results of state of the environment soil quality monitoring undertaken in the Wellington region between 2000 and 2010, and summarises the results of regional soil stability surveys undertaken in 2002 and 2010. Monitoring the state of the environment is a specific requirement for regional councils under Section 35(2)(a) of the Resource Management Act (RMA) 1991.

1.1 Report purpose

This technical report is one of eight covering air, land and water resources prepared with the primary purpose of informing the review of Greater Wellington's five regional plans. These plans were established to sustainably manage the region's natural resources, including soils. The review of the regional plans follows the recently completed review of the overarching Regional Policy Statement (RPS) for the Wellington region (GWRC 2010).

The focus of the eight technical reports is on providing an up-to-date analysis of monitoring information on state and trends in resource health as opposed to assessing the effectiveness of specific policies in the existing RPS (WRC 1995) or regional plans. Policy effectiveness reports were prepared in 2006 following the release of Greater Wellington's last formal State of the Environment (SoE) report, *Measuring up* (GWRC 2005).

The last technical report supporting SoE reporting on soil health in the Wellington region was prepared by Croucher (2005); this report focussed on soil quality monitoring undertaken between 2000 and 2004.[1]

[1] Greater Wellington also prepares annual summary reports documenting SoE monitoring results obtained in the last financial year. Refer to Sorensen (2010) for the most recent annual soil quality monitoring report.

1.2 Report scope

This report assesses the results of routine soil quality monitoring undertaken in the Wellington region over the period 2000 to 2010 inclusive. Specifically, it assesses the state of soil health under selected land uses and, in the case of dairy and vegetable growing land uses, examines temporal changes in soil quality over the reporting period. This report also summarises the results of the regional soil stability surveys undertaken in 2002 and 2010.

1.3 Report outline

The report comprises seven sections:

- Section 2 outlines Greater Wellington's soil quality monitoring network, sampling methods and soil quality indicators. It also presents the background, objectives and methods of the soil stability surveys.

- Section 3 provides an overview of land and soil resources in the Wellington region and key pressures likely to impact on their health.

- Section 4 presents an analysis of the current state of soil quality based on the most recent round of monitoring of each land use type, and an assessment of soil stability, disturbance and intactness and bare soil undertaken in 2010.

- Section 5 assesses temporal trends in soil quality on the dairy farm and vegetable growing monitoring sites sampled on three occasions between 2000 and 2010. The results of regional soil stability surveys undertaken in 2002 and 2010 are also compared.

- Section 6 discusses the main findings from Sections 4 and 5, highlighting the key issues affecting soil quality and stability. Sustainable land management practices are also briefly outlined, along with some key limitations associated with the existing soil monitoring programmes.

- Section 7 presents conclusions and recommendations.

2. Overview soil monitoring programmes in the Wellington region

2.1 Soil quality monitoring

2.1.1 Background

Greater Wellington became involved in a national soil quality programme known as “The 500 Soils Project” in 2000. After completion of the project in 2001, Greater Wellington implemented a monitoring programme to continue assessing the quality of soils throughout the Wellington region.

As part of the 500 Soils Project a standard set of sampling methods, as well as several soil quality indicators involving different physical, chemical and biological soil properties, were identified to assess dynamic properties of soil quality. A value or range of values for each of the properties was derived enabling the relationship between the quantitative measure of the soil attribute and its soil quality rating to be determined. The use of these standard methods and properties allows comparisons of similar soils and land uses both within the region and nationally. These sampling methods and properties were adopted for use in Greater Wellington’s soil quality monitoring programme.

2.1.2 Monitoring objectives

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

- Provide information on the physical, chemical and biological properties of soils in order to assess overall soil health;
- 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 a mechanism to determine the effectiveness of regional policies and plans.

2.1.3 Monitoring sites and frequency

The monitoring programme currently consists of 118 sites on the different Soil Orders across the region under different land uses (Figure 2.1, Appendix 1). The frequency of sampling is dependent on the intensity of the land use; dairying, cropping and vegetable growing sites are sampled every 3-4 years, drystock, horticulture and exotic forestry sites are sampled every 5-7 years, while native forest sites are sampled every 10 years.

A definition of each land use category used in the soil quality monitoring programme is given in Table 2.1.

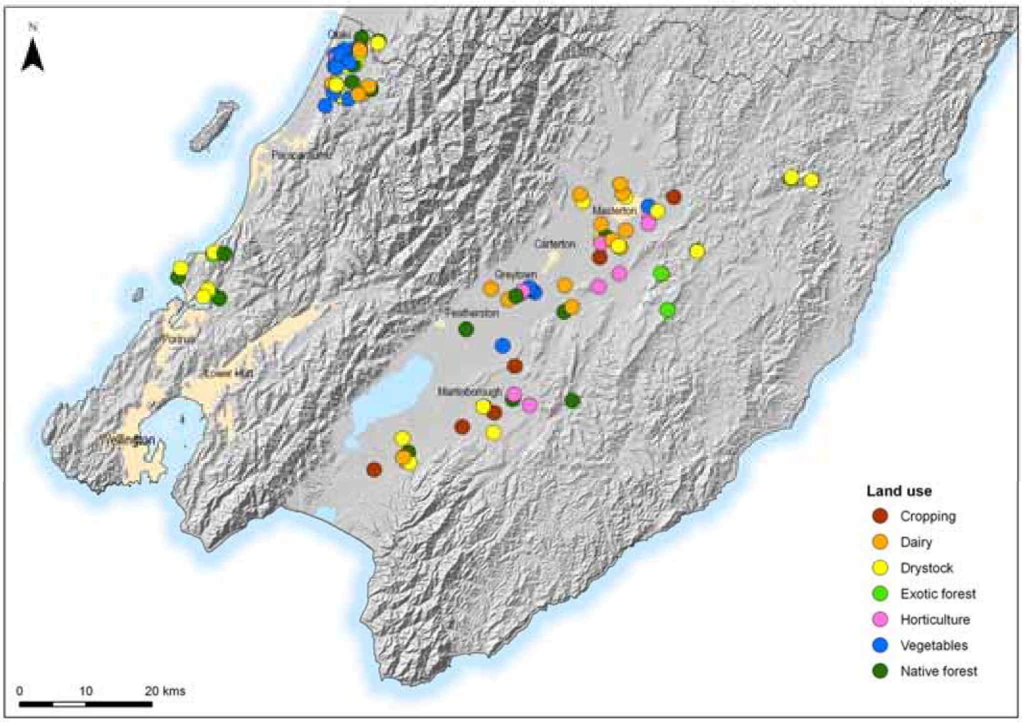


Figure 2.1: The 118 soil quality monitoring sites throughout the Wellington region

Table 2.1: Definitions of land use categories

Land use category	Definition
Cropping	Annual crops usually grown on a rotational system with pasture. Includes maize, barley, wheat, lucerne, peas, fodder crops and pasture for silage production.
Dairy	Pasture grazed by cattle for the purpose of milk production for use in dairy products.
Drystock	Pasture grazed by livestock other than dairy cattle. Includes sheep, beef cattle, horses, goats and other domesticated animals.
Exotic forest	Plantations of exotic tree species grown for timber production. Generally Radiata pine but can also include Macrocarpa and Douglas-fir.
Horticulture	Permanent row plantations, including trees and vines. Includes pip fruit, stone fruit, berry fruit, olives and grapes.
Vegetables	Any vegetable crop grown commercially for human consumption.
Native forest	Native forest and scrub made up of indigenous species. Undeveloped and undisturbed by land use.

2.1.4 Sampling methods

At each monitoring site a 50 m transect is laid out. Soil cores 2.5 cm in diameter to a depth of 10 cm are taken every 2 m along the transect (Figure 2.2a). The 25 individual cores are bulked and mixed in preparation for chemical and biological analyses to determine the organic resources, acidity and fertility of the soil and concentrations of trace elements.

Three undisturbed (intact) soil samples are also obtained from each site (Figure 2.2b). The intact soil cores are collected at 15, 30 and 45 m intervals along the transect by pressing steel liners (10 cm in width and 7.5 cm in depth) into the top 10 cm of soil. These intact soil cores are used to determine the physical properties of the soil such as dry bulk density, porosity and water holding characteristics.

For vegetable growing sites, an additional sample is also collected to assess aggregate stability. The sample is collected at the same interval as the intact cores by cutting a vertical block of soil with a spade approximately 10 cm square (10 cm high x 10 cm wide) and 10-12 cm thick from a fresh vertical soil face. Care is taken to ensure a sufficient volume of soil (approximately 3 kg) is collected enabling three replicate analyses on each sample. Samples also need to be carefully handled to avoid crushing, smearing or altering the aggregates in any way.

Details of the laboratory methods used can be found in Appendix 2.

Figure 2.2: (a) Collecting a composite of core samples along a transect using a soil corer. (b) One of three intact core samples taken at each site to establish the physical properties of the soil.

2.1.5 Soil quality indicators

Seven primary soil properties are measured and used as indicators of soil quality (Table 2.2 and Appendix 3): bulk density, macroporosity, total carbon, total nitrogen, anaerobic mineralisable nitrogen (AMN), soil pH and Olsen P. In addition, concentrations of various trace elements are analysed and, for vegetable growing sites, aggregate stability is measured. Although not a soil quality indicator, the ratio of carbon to nitrogen (C:N) is also reported, because it is a useful indicator of change. The soil properties can be grouped into specific areas of soil quality: physical condition, organic resources, acidity, fertility and trace elements. Together, these indicators provide an overall picture of soil health.

Table 2.2: Indicators used for soil quality assessment (adapted from Hill and Sparling (2009)). See Appendix 3 for more detail.

Soil property	Indicator	Soil quality information	Why is this indicator important?
Physical condition	Bulk density	Soil compaction	Bulk density is the weight of a soil and is used for volumetric conversions. A high bulk density indicates a compacted or denser soil. Compacted soils will not allow water or air to penetrate, do not drain easily and restrict root growth, adversely affecting plant growth. There is also potential for increased run-off and nutrient loss to surface waters.
	Macroporosity	Soil compaction and degree of aeration	Macropores are important for air penetration into soil and are the first pores to collapse when soil is compacted. Low macroporosity adversely affects plant growth due to poor root environment, restricted air access and N-fixation by clover roots. It also infers poor drainage and infiltration (see bulk density).
	Aggregate stability	Soil structure breakdown – how resistant soil crumbs are to breakage.	Aggregate stability is a measure of the stable crumbs in soil that are of a desirable size, and resist compaction, slaking, and capping of seedbeds. It is useful to measure at horticultural and cropping soils because aggregates are affected by cultivation. A stable “crumbly” texture lets water quickly soak into soil, doesn’t dry out too rapidly, and allows roots to spread easily.
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 of the potential for nitrogen to leach into underlying groundwater.
	Anaerobic mineralisable nitrogen (AMN)	Surrogate for 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 the plants, and is also used as a surrogate measure of the microbial biomass.
Acidity	Soil pH	Soil acidity	Most plants and animals have an optimal pH range for growth. The pH of a soil also controls the availability of many nutrients to plants and the solubility of some trace elements. Soil pH is greatly influenced by the application of lime and fertilisers.
Fertility	Olsen P	Plant-available phosphate	Phosphorus (P) is an essential nutrient for plants and animals. Plants get their P from phosphates in the soil. Olsen P is a measure of the amount of phosphorus that is available to plants. Excessive levels can increase loss to waterways, contributing to eutrophication (nutrient enrichment).
Trace elements	As, Cd, Cr, Cu, Ni, Pb and Zn*	Accumulation of trace elements	Some trace elements are essential micro-nutrients for plants and animals while others are not. 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 activities.

* Arsenic, cadmium, chromium, copper, nickel, lead and zinc

2.1.6 Soil quality guidelines

The soil properties themselves do not measure soil quality, rather soil quality is a value judgement about how suitable a soil is for its particular land use. A group of New Zealand experts in soil science developed soil response curves for each of the soil properties, and established critical values or optimal ranges for the assessment of soil quality for the predominant soil orders under a number of different land uses. However, interpretive frameworks are still under development, particularly when examining environmental rather than production criteria (Hill & Sparling 2009). As a result, the critical values and optimal ranges used to assess soil quality in this report are often related to effects on production but effects on the environment can also be inferred. The critical values and optimal ranges taken from Hill and Sparling (2009) are displayed on graphs in Section 4; the actual values can be found in Appendix 4.

The trace element results in this report have been compared against the soil limits presented in the New Zealand Water and Wastes Association (NZWWA 2003) 'Guidelines for the Safe Application of Biosolids to Land in New Zealand' (referred to as the biosolids guidelines). While guidelines containing soil contaminant values like the biosolids guidelines have been written for a specific activity (biosolids application), the values are generally transferable to other activities that share similar hazardous substances (Ministry of Agriculture and Forestry 2008). For example, the NZWWA biosolids guidelines have been used by some regional councils to measure and assess cadmium present in soils as a result of phosphate fertiliser application, rather than the application of biosolids (Ministry of Agriculture and Forestry 2008). Other guidelines are available such as the Health and Environmental Guidelines for Selected Timber Treatment Chemicals (Ministry for the Environment 1997) for assessing the concentrations of specific trace elements. The biosolids guideline values for the selected trace elements presented later in this report are presented in Appendix 4.

Cadmium results have also been compared to the Tiered Fertiliser Management System (TFMS) from the New Zealand Cadmium Management Strategy (2011). The strategy recommends adjusting results to allow for any differences in sampling depth. The samples in this report were taken at a depth of 0–10 cm based on the methods in Hill and Sparling (2009), compared to depths of 0–7.5 cm for uncultivated land and 0–15 cm for cultivated land, which the TFMS is based on. Conversions factors can be used to convert previous sampling approaches, but these were not available at the time of preparing this report.

2.2 Soil stability monitoring

2.2.1 Background

It is important to understand how well soil is being kept in place on the land so it continues to be available as a resource for farming, forestry and conservation. It is equally important to understand how much soil is being lost through erosion, deposition or land use related disturbance.

To help understand the state of soil in the Wellington region, a monitoring programme (referred to as the soil stability monitoring programme in this report) was established to monitor soil stability, intactness and disturbance and bare soil. The soil stability monitoring programme is a point sample survey based on the principles and methods in Burton et al. (2009), and summarised in this report. Two soil stability surveys have been undertaken, one covering the period 2001–2003 and the other 2010.

2.2.2 Monitoring objectives

The objectives of Greater Wellington's soil stability monitoring programme are to:

- Estimate the state of soil (intactness or disturbance) in the Wellington region;
- Identify the nature of disturbance;
- Measure the extent of bare soil;
- Identify pressures contributing to increased soil disturbance by land use, and erosion by natural processes; and
- Assess responses to soil disturbance, such as conservation planting, or retirement and reversion.

2.2.3 Monitoring methods

Aerial photographs are used to assess soil stability and associated information at sample points across the entire region. The sample points (total of 2,039) are distributed at 2 km intervals on the New Zealand Map Grid (NZMG). Although spatially regular, this sample design is random with respect to land use and other factors which are unrelated to the map grid (Crippen & Hicks 2011).

At each 2 km interval a 1 ha square is created centred on the grid intersection, which is a sample point (Figure 2.3). Each sample point is viewed at a scale of 1:10,000, zooming to smaller scales to inspect detail when necessary, and to larger scales to view points in the context of the surrounding terrain.

To determine the amount of bare ground at each sample point, a 100 dot grid is applied over the 1 ha (Figure 2.4). The percentage of bare soil is then calculated from the number of points residing on bare soil.

The aerial photographs used for the first survey spanned three years from 2001 to 2003. In 2001, the middle of the Wellington region was photographed. In 2002, most of the northern areas and some of the lower Wairarapa Valley were photographed. In 2003, aerial photographs for the rest of southern Wairarapa were taken. Aerial photos used for the re-survey were all taken in 2010. For the purposes of this report, the first survey is considered an interpretation of soil stability at 2002 and the re-survey an interpretation of soil stability at 2010.

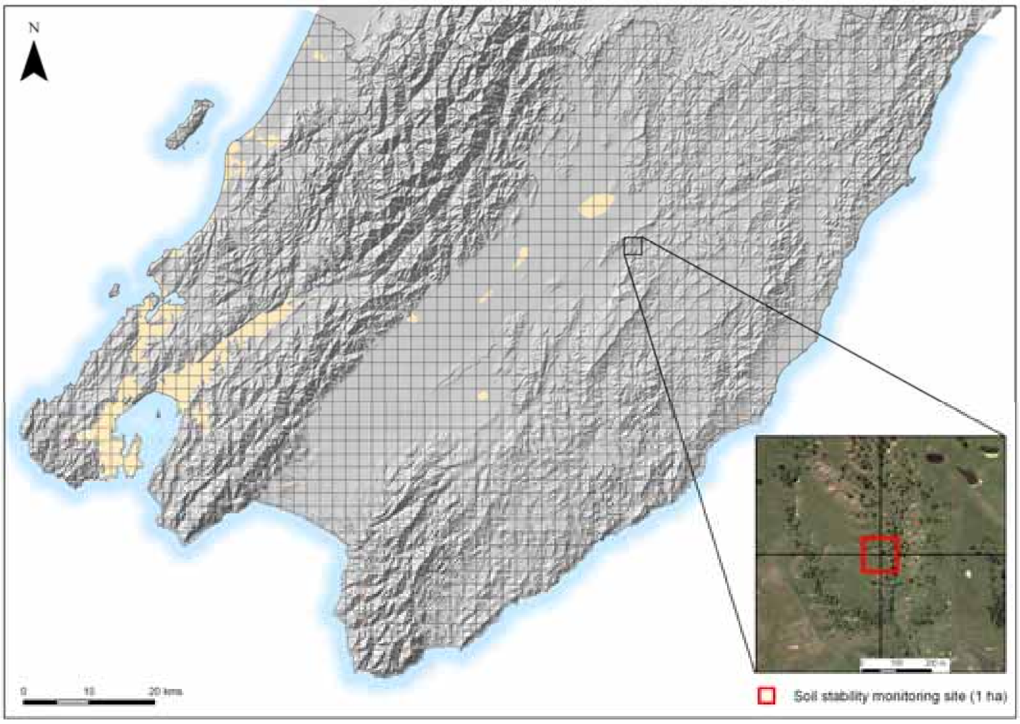


Figure 2.3: Soil stability monitoring sites (total 2,039), located on the intersections of a 2 km grid of the Wellington region

Figure 2.4: Soil stability monitoring site, showing the 100 dot grid used to calculate the amount of bare soil

2.2.4 Survey attribute data

At each of the sample points, the surface area is assessed and given one of the following categories which are used for the analysis of soil stability and the type of disturbance:

- **Stable:** shows no signs of past erosion and is completely vegetated (unless topsoil is disturbed by land use).

- **Erosion-prone:** unstable surfaces but are inactive. Shows signs of past erosion but currently not eroding as erosion scars have healed and are well vegetated (unless topsoil is disturbed by land use). Erosion has usually occurred at least a decade prior to photography.

- **Eroded:** unstable surfaces and recently disturbed. The erosion scars are re-vegetating. Erosion is still identifiable and has usually occurred in the decade prior to photography.

- **Eroding:** unstable surfaces and freshly disturbed. The erosion scars are active with a large proportion de-vegetated. Erosion can be easily identified, and has usually occurred in the year prior to the photography.

Other associated information was recorded for each of the sampling points, including:

- Land use;
- Landform;
- Primary vegetation;
- Secondary vegetation;
- Nature of disturbance (land use related and natural); and
- Bare soil (using cluster sampling).

3. Overview of land and soil resources in the Wellington region

Land and soil are valuable resources in the Wellington region. Together they are used to support a wide range of land use types including agriculture, horticulture, forestry and urban development. Land management practices associated with all land use types can have an impact on the land and health of the soil. This section outlines the land and soil resources in the region and some of the pressures being placed on them. See Tidswell et al. (2012) for information on specific consented activities with potential to impact on soil health.

3.1 Soil resources

At the time of preparing this report, information on soils within the Wellington region was limited[2]. The New Zealand Land Resource Inventory (NZLRI) provides some information, as well as previous soil mapping work documented by Heine (1975) (Figure 3.1).

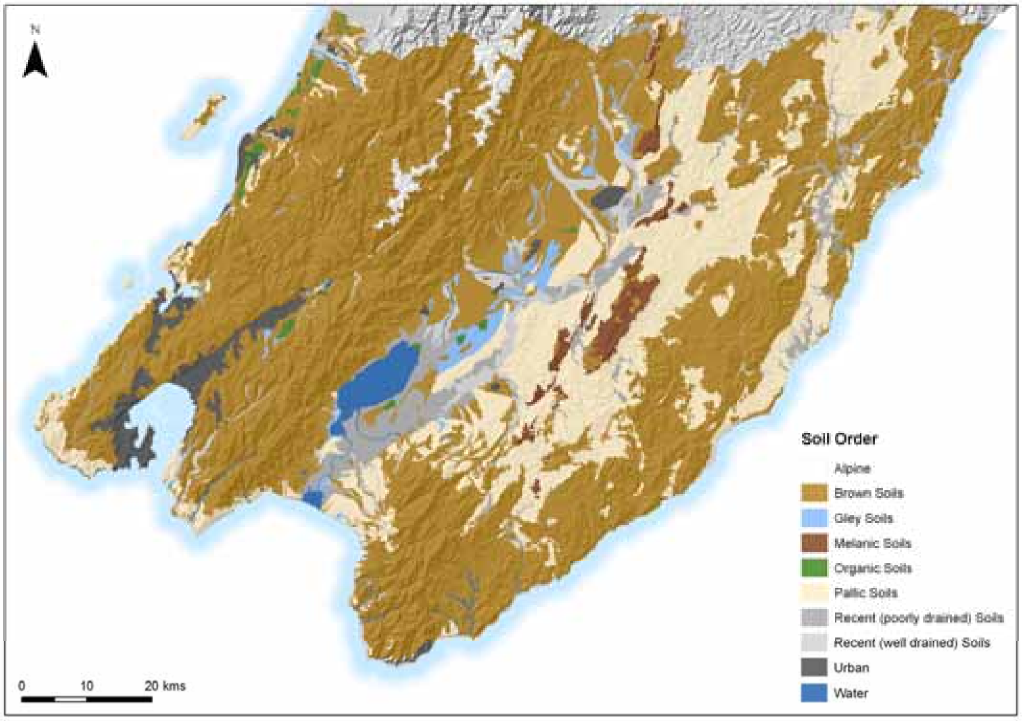


Figure 3.1: Soil Orders of the Wellington region based on NZLRI and Heine (1975)

The most dominant Soil Order in the region is Brown Soils. They cover over 62% of the region, including most of the western side of the region, the Tararua and Rimutaka ranges and parts of the eastern Wairarapa hill country. Brown Soils are also the most extensive in New Zealand, occurring in places in which summer dryness is uncommon and that are not waterlogged in the winter (Hewitt 1998).

2 In 2011 – when this report was being prepared – Landcare Research was completing more comprehensive soil assessments for parts of the Wellington region as part of S-Map, a national project to improve information on soil properties throughout New Zealand.

The other major Soil Order in the region is Pallic Soils. These soils cover just over 20% of the region and are located mostly throughout the eastern Wairarapa hill country and the hills of Wellington city's south coast, and northern Porirua. Pallic Soils are formed predominantly on loess or sediments derived from schist or greywacke (McLaren & Cameron 1996). They are also pale in colour due to low contents of iron oxides, and they are susceptible to erosion because of high potential for slaking and dispersion (Hewitt 1998).

Another Soil Order found in the region is Recent Soils. These soils make up 7.8% of the land area, and are found predominantly in the Wairarapa Valley and near Otaki. Recent Soils occur in young landscapes, including on alluvial plains and unstable steep slopes, and show only minimal soil profile development because of their youthfulness (McLaren & Cameron 1996). Figure 3.1 differentiates between the well drained and poorly drained Recent Soils.

A small area (1.5% of the region) in the eastern Wairarapa hills contains Melanic Soils. Melanic Soils are well structured, have high base saturations and a very dark A horizon due to their parent materials being rich in calcium and/or magnesium (McLaren & Cameron 1996). The Melanic Soils in the Wairarapa are developed on the areas of calcareous rocks (limestone).

Gley Soils make up only 1.1% of the region, and are located in small areas mainly in the Wairarapa Valley and the Upper Hutt area. Gley Soils are poorly drained, and occur in places with high water-tables. While they have poor drainage, Gley Soils can be artificially drained to form productive agricultural land (McLaren & Cameron 1996).

Unlike most regions in the North Island, the Wellington region does not contain Allophanic or Pumice soils as there are no volcanic deposits.

3.1.1 Versatile soils

The Wellington region contains a diverse range of soils reflecting variations in parent material composition and texture, age of soil development, climate, landscape position and drainage. These soils exhibit a range of different soil properties and characteristics and present different opportunities and constraints to land use. Along with mapping the soil types for the region, the NZLRI and its derived assessments identify the capacity of land for sustained agronomic production, referred to as land use capability (LUC). LUC classification is an assessment of the land's capacity for sustained productive use, while taking into account physical limitations, including climate, soil conservation needs and management requirements (Lynn et al. 2009). There are eight LUC classes, with limitations to use increasing, and versatility of use decreasing from LUC Class 1 to LUC Class 8 (Figure 3.2).

Figure 3.3 and Table 3.1 present the LUC classes for the Wellington region from the NZLRI. Over 163,000 ha or a total of 20.1% of the region's soils occur in LUC Classes 1 to 4, which are considered the most versatile soils. Nearly 75% of soils are classed as LUC Classes 6 to 8, and only a very small proportion of the region's soils are classed LUC Class 5.

Increasing Limitations to Use ↓	LUC Class	Arable Cropping Suitability*	Pastoral Suitability	Production Forestry Suitability**	General Suitability	Decreasing Versatility of Use ↓
	1	High	High	High	Multiple Use Land	
	2	↓	↓	↓		
	3					
	4	Low				
	5	Unsuitable			Pastoral or Forestry Land	
	6					
	7		Low	Low		
	8		Unsuitable	Unsuitable	Catchment Protection	

Figure 3.2: Increasing limitations to use and decreasing versatility of use from LUC Class 1 to LUC Class 8 (Lynn et al. 2009)

* Includes vegetable growing.

** LUC Classes with a major wetness limitation, and those units in low rainfall areas (<500 mm/yr), or those occurring on shallow soils (<45 cm) are normally not suited to production forestry.

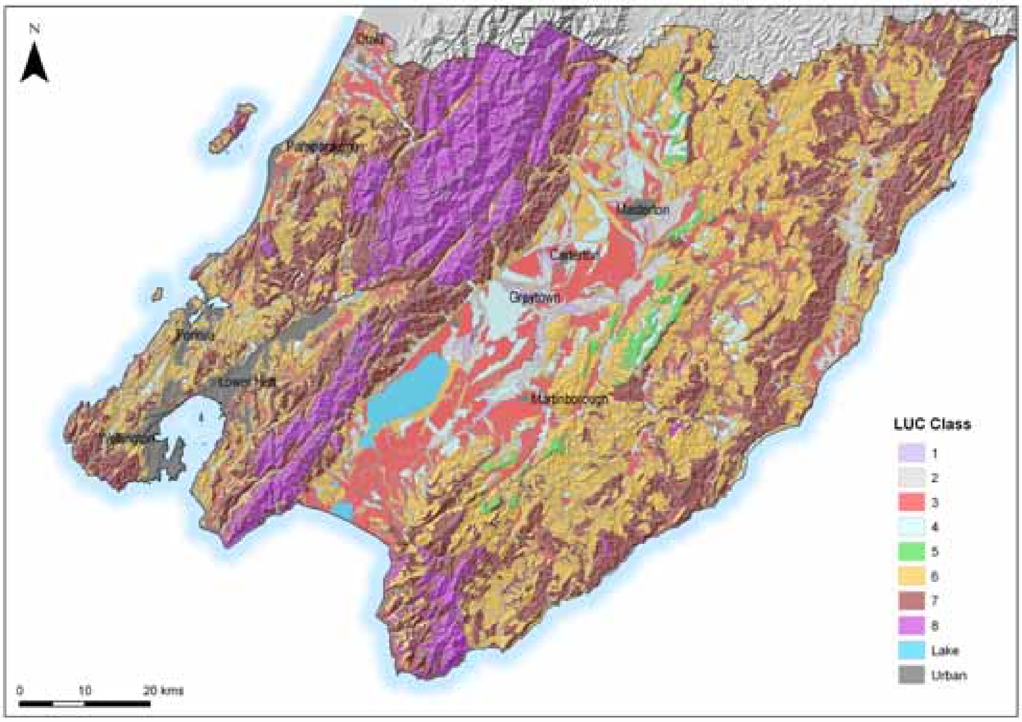


Figure 3.3: Distribution of soils by LUC Class in the Wellington region according to the NZLRI

The region's most versatile soils (LUC Classes 1 to 4) occur predominantly in the low lying and fertile areas, particularly around Otaki and parts of the Wairarapa Valley, but also in Upper Hutt, and parts of the eastern Wairarapa, including the Whareama Valley and Riversdale (Figure 3.3). LUC Classes 6 to 8 are found mostly in the mountainous parts of the region including the Tararua and Rimutaka ranges, but also in the hills of Wellington city and Lower Hutt, and large areas of the eastern Wairarapa hill country.

Table 3.1: Proportion of each LUC Class in the Wellington region

LUC Class	Area (ha)	Area (% of region)	Cumulative % of region
1	5,188	0.64	0.64
2	29,645	3.65	4.29
3	87,566	10.78	15.07
4	40,975	5.05	20.12
5	8,458	1.04	21.16
6	273,314	33.65	54.81
7	231,755	28.53	83.34
8	103,101	12.69	96.03
Lake	8,850	1.09	97.12
River	2,319	0.29	97.41
Urban	21,011	2.59	100

Versatile soils are an important resource for the region because they offer the most options for land use, including food production, horticulture and agriculture. However, because the region's most versatile soils are often located near urban centres the land is also under pressure from urban development. The on-going reduction or loss of versatile soils can limit future production options and require additional inputs or management to maintain a given level of output if attempted on soils with less versatility (Rutledge et al. 2010).

To assess how much of the region's most versatile soils have been lost to urbanisation over recent years, comparisons were made between the urban areas mapped in Heine (1975), and the areas developed into urban as determined from the interpretation of Territorial Authority zonings and aerial photographs taken in 2010 (Table 3.2). This assessment shows a total of 4,379[3] ha of land have been developed into urban areas from the various LUC Classes, which equates to an increase in urban area of approximately 20% since 1975. Figure 3.4 shows where this urban development has occurred throughout the region.

The most versatile soils (LUC Classes 1 to 4) experienced the highest rates of urbanisation, with 5.9% of the resource lost to urbanisation. Out of all the LUC classes, and although affecting a relatively small area, LUC Class 1 soils experienced the highest level of conversion with 3.4% of the original extent having been converted into urban land use. The majority of LUC Class 1 soils lost was located near Otaki and Greytown. The loss of other more versatile soils, predominantly LUC Class 3, occurred near the urban areas of Masterton, Carterton, Featherston, Martinborough, Upper Hutt and Paraparaumu.

[3] Caution should be given to the exact numbers because urban areas mapped in the NZLRI were mapped at a broader scale than the scale used to interpret the aerial photographs.

Table 3.2: Distribution of soils and the urbanisation trends by LUC Class in the Wellington region, determined from a comparison between Heine (1975) and aerial photographs (2010)

LUC class	Area converted to urban (ha)	Area converted to urban (% of LUC Class)	Cumulative % of LUC class
1	179	3.4	3.4
2	92	0.3	3.7
3	1,096	1.3	5.0
4	362	0.9	5.9
5	0	0	5.9
6	2,304	0.8	6.7
7	327	0.1	6.8
8	20	0	6.8
Total (increase in urban area)	4,379		

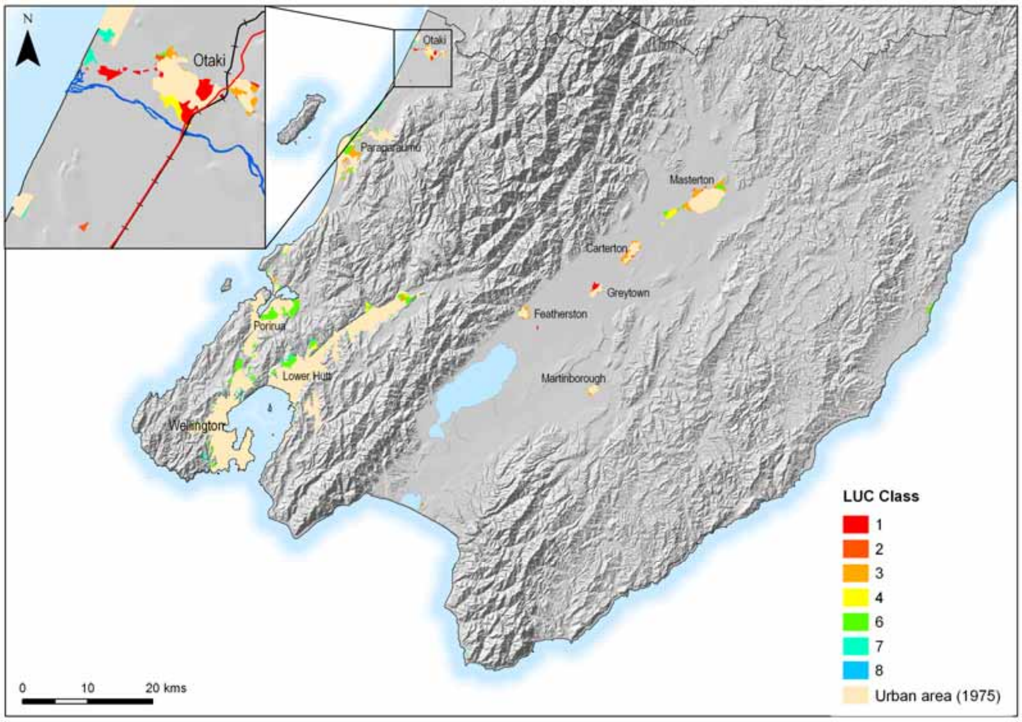
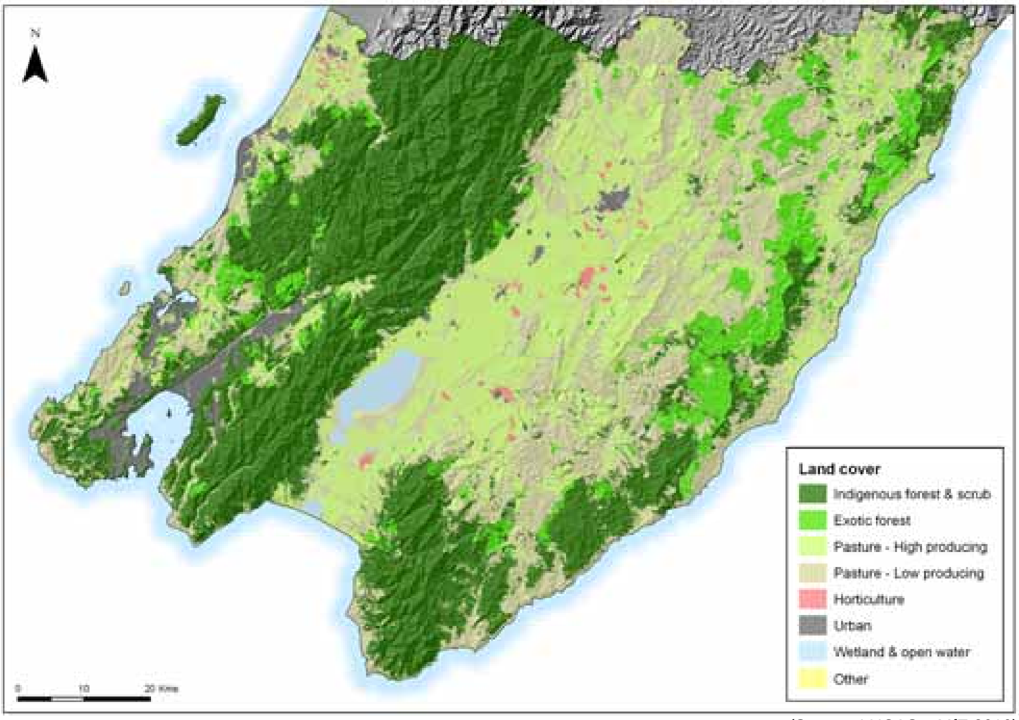


Figure 3.4: Areas of urban development by LUC Class from 1975 to 2010 in the Wellington region

The greatest area of conversion occurred on LUC Class 6, with 2,304 ha of the original extent converted into urban area. However, because LUC Class 6 makes up over a third of the region, the loss accounted for just 0.84% of the original LUC Class 6 area. Most of the conversion on LUC Class 6 land occurred in the residential development areas of north Wellington, Porirua and the hills of the Hutt Valley.

3.2 Land cover

Similar to information on soils within the region, information on current land cover and land use is also limited. The most up-to-date land cover information for the region is based on the interpretation of aerial photographs taken in 2008 by the (Ministry for the Environment 2010) (Figure 3.5).



(Source: LUCAS – MfE 2010)

Figure 3.5: Land cover of the Wellington region, derived from aerial photographs taken in 2008

The Wellington region consists of over 812,000 ha. Close to half of the region is in pasture, with 21.6% high producing pasture[4], and 28.0% low producing pasture[5]. The majority of high producing pasture is located within the Wairarapa Valley and near Otaki, while the low producing pasture is predominantly located in the eastern hill country of the Wairarapa, and also the hill country of Wellington and Porirua cities.

Over 290,000 ha (37.0%) of the region's land area remains under indigenous forest cover, with a large proportion of this found in the Tararua Forest Park. Exotic forest is found throughout the hill country on the western and eastern sides of the region, but makes up a smaller proportion of the land area (8.6%). There is just over 4,000 ha (0.5%) of horticulture (including cropping) in the region, located mainly around Otaki and localised areas in the Wairarapa Valley. Urban areas occupy 2.4% of the region, and are concentrated mainly in the western side of the region around Wellington city, Porirua and the Hutt Valley.

[4] High producing pasture is defined as 'sown pasture' – pasture with a medium to high dry matter production, including rye grass and clover (Ministry of Works and Development 1979).

[5] Low producing pasture is defined as 'adventive grassland'– includes native grasses and browntop and other pasture species with low dry matter production (Ministry of Works and Development 1979).

3.3 Land use

General land use can be inferred from land cover information, but information to show specific land uses are unavailable (especially for pasture and horticulture). Understanding how the land is being used and the land management practices being used can help us understand what pressures are being placed on the land and soils of the region.

Regional land use information has been recorded in recent soil stability surveys (Crippen & Hicks 2004); Crippen & Hicks 2011). The surveys record information (including land use) for all points (total 2,039) across the region through interpreting aerial photographs (see Section 2.2 for more details). While the soil stability surveys are point sample surveys, they are sufficiently representative to draw conclusions about land use within the region (Crippen & Hicks 2011). Figure 3.6 shows the percentage of land uses occupying the region's land area for the periods 2002[6] and 2010.

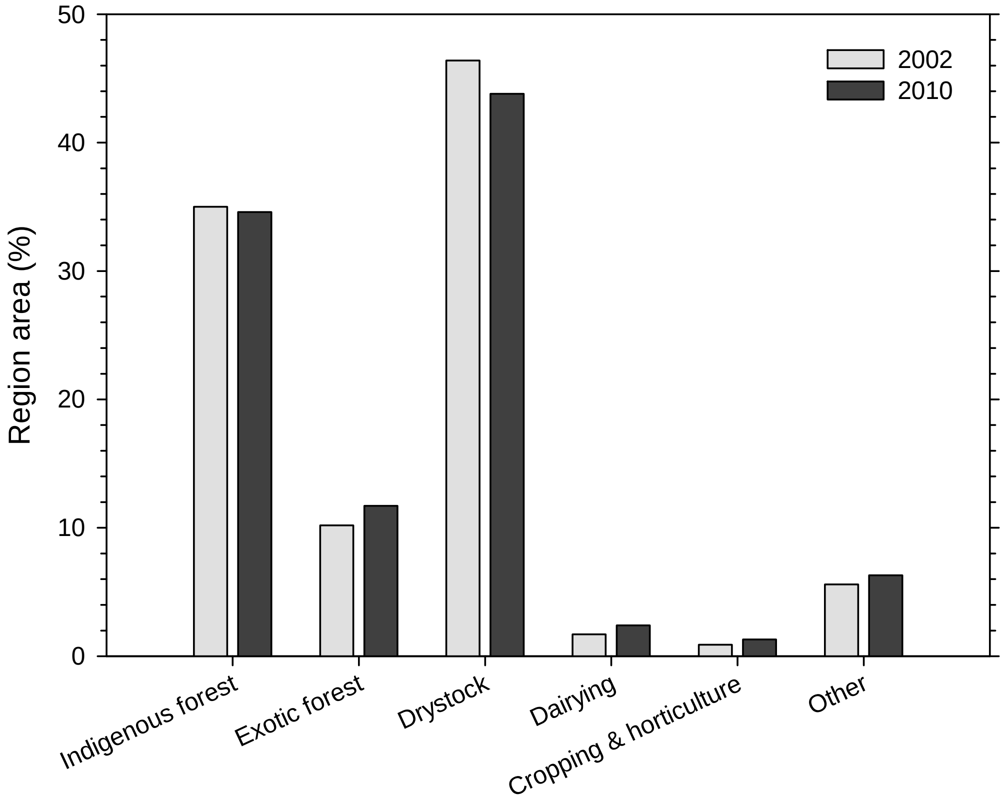


Figure 3.6: Land use within the Wellington region in 2002 and 2010 (from Crippen & Hicks 2011)

The largest land use change between 2002 and 2010 was a reduction in drystock farming by 2.6% of the region's land area, or over 21,000 ha. In contrast, exotic forest plantations increased across the region by 1.5% or over 12,000 ha. This suggests a large proportion of the additional 12,000 ha of exotic forest since 2002 has been planted on land previously used for drystock farming, most probably the steeper land that isn't sustainable for drystock farming. Small increases are also evident for dairying (0.7% of region's land

[6] The aerial photographs which were interpreted were taken from 2001 to 2003 across the region. As outlined in Section 2.2.3, for the purposes of this report the date is reported as 2002.

area and approximately 5,600 ha) and the 'other' category (0.7%), which includes urban areas. Indigenous forest, and cropping and horticulture remained the most constant land uses, reducing by 0.4% of the region's land area, and increasing by 0.4%, respectively.

3.3.1 Livestock numbers

With approximately half of the Wellington region covered in pasture, agriculture is an important industry for the region. Figure 3.7 shows that while there are still significantly more sheep than all other livestock in the region, sheep numbers have reduced constantly since 1990. In contrast, beef cattle and deer numbers remained reasonably consistent (although numbers for both have decreased since 2006) and dairy cattle increased significantly from 62,521 in 1990 to 92,375 in 2010.

While dairy cattle numbers have increased across the region, the effective farming area in terms of hectares of dairy farming has decreased by 11% (Table 3.3) (this is in contrast to information from the soil stability surveys). In addition to the reduction in farming area, the average herd size for the region increased 33% from 299 in 2002 to 399 in 2009. These two factors results in an increase in the average stocking rate from, on average, 2.54 cows per hectare of dairy farm land in 2002/03 to 2.80 cows per hectare in 2009/10.

Nationally, dairy farming continues to increase in area and dairy cow numbers are at a record high with a total in 2009 of over 4.4 million; the stocking rate of 2.81 cows per hectare is the highest stocking rate recorded (DairyNZ 2010). While this information suggests that the effective area of dairy farming has decreased in the Wellington region, the opposite to the national trend, the increases in average herd size and stocking rates in the Wellington region are very similar to the overall trends in New Zealand.

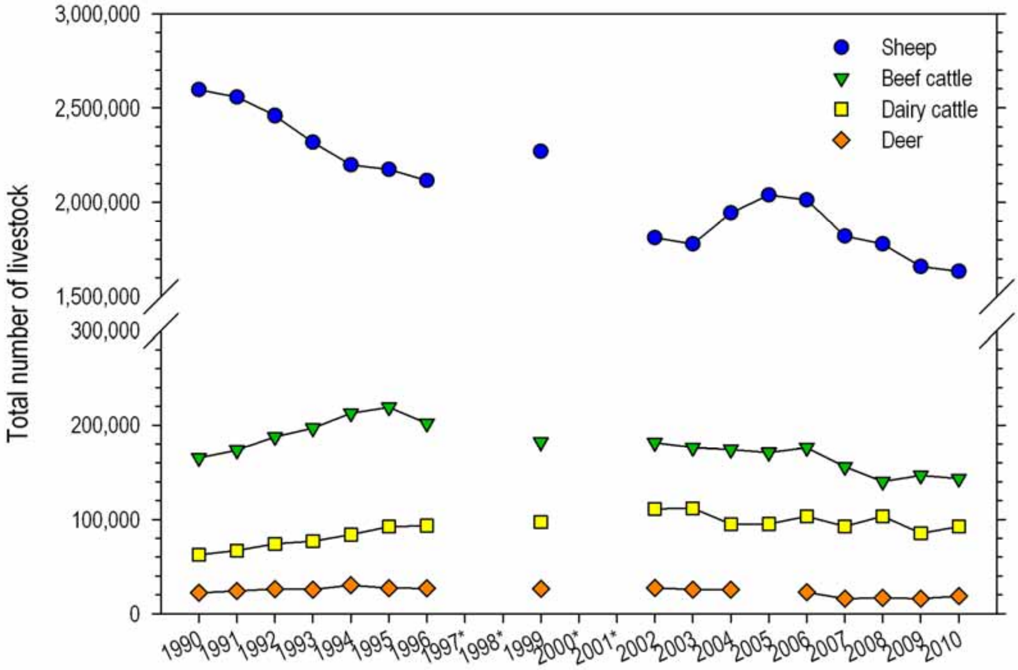


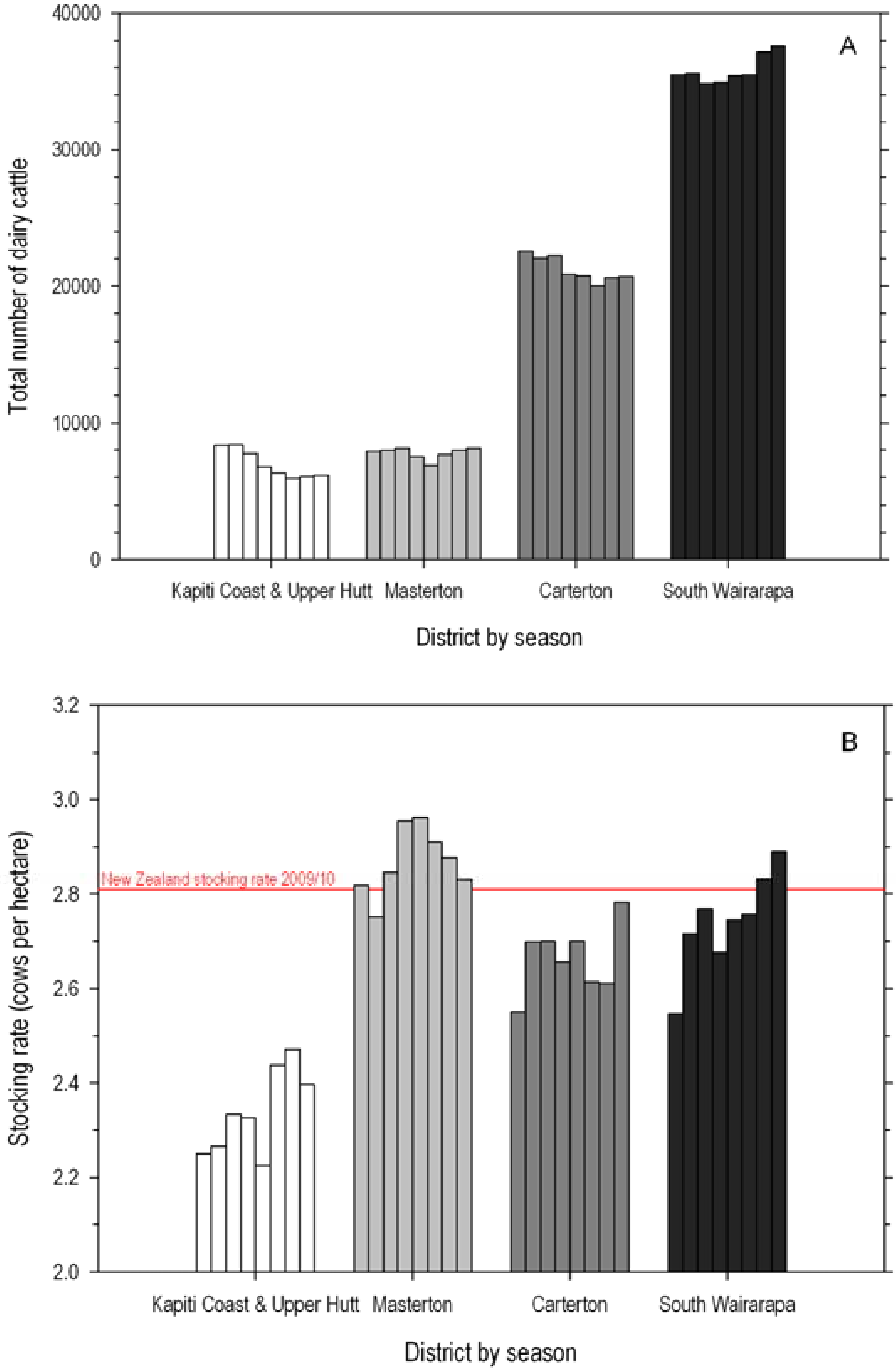
Figure 3.7: Numbers of livestock within the Wellington region, 1990-2010
(Source: Dairy NZ 2010) * Data not available

Table 3.3: Dairy farming area, herd size and stocking rates for both the Wellington region and all of New Zealand
(Source: DairyNZ 2010)

Season	Effective farming area (ha)		Average herd size		Average stocking rate (cows per hectare)	
	Wellington	New Zealand	Wellington	New Zealand	Wellington	New Zealand
2002/03	29,235	1,463,281	299	285	2.54	2.57
2003/04	27,855	1,421,147	311	302	2.66	2.72
2004/05	26,964	1,411,594	332	315	2.71	2.74
2005/06	26,307	1,398,966	347	322	2.66	2.73
2006/07	25,778	1,412,925	352	337	2.69	2.79
2007/08	25,629	1,436,549	371	351	2.70	2.79
2008/09	26,181	1,519,117	390	366	2.74	2.79
2009/10	25,898	1,563,495	399	376	2.80	2.81
% change 2002–2010	-11	7	33	32	10	9

Looking at the region's dairy farming on a district basis, South Wairarapa contains nearly half of all the dairy cattle in the Wellington region. It is also the district with the most growth in dairy cattle numbers, increasing from 35,466 in 2002/03 to 37,577 in 2009/10 (Figure 3.8). The second largest dairying district in the region is Carterton, with the combined dairy cattle numbers from the districts of Kapiti Coast and Upper Hutt, along with dairy cattle numbers in Masterton, making up smaller proportions of the total dairy cattle numbers for the region.

Although South Wairarapa and Carterton contain the majority of dairy cattle in the region, Masterton has until recently contained the highest stocking rate, peaking at 2.96 cows per hectare in 2006/07 (Figure 3.8); although this decreased to 2.83 in 2009/10, it is still above the national average stocking rate (Table 3.3). Stocking rates in both South Wairarapa and Carterton have steadily increased since 2002/03, peaking at 2.89 and 2.78 cows/ha, respectively, in 2009/10.



(Source: Dairy NZ 2010)

Figure 3.8: Total number of dairy cattle (A) and dairy cattle stocking rates (cows per hectare) (B) for each district with dairy cattle in the Wellington region, 2002/03 to 2009/10. Each bar represents a milking season, with the left-most bar for each district representing 2002/03 and the right-most bar representing 2009/10.

3.3.2 Horticulture

A small proportion of the Wellington region is used for various horticultural uses. Information from MfE (2010) suggests that in 2008 approximately 0.5% of the region's land was used for horticulture, while Crippen and Hicks (2011) determined that in 2010 1.4% of the region's land was used for cropping and horticulture. Although minor in terms of the proportion of the region's land resource, horticulture is an important land use for the region, especially in areas around Otaki, Te Horo, Greytown and Martinborough.

Although Statistics New Zealand data suggest that horticulture (excluding vineyards) has declined by over 40% in the region from 2002 to 2007 (Table 3.4), accurate information on horticultural land use is difficult to obtain and more detailed analysis of information would be required before it could be established if horticulture (particularly orchards and vegetable growing) has in fact decreased over this period[7]. More information is available for vineyards from the New Zealand Winegrowers Vineyard Surveys, which shows that the area of vineyards has grown by 44% from 2003 to 2009 (Table 3.4). However, the rate at which vineyards have increased has slowed in the past few years, and the region remains only a minor producer of wine in New Zealand.

Table 3.4: Area (hectares) of land used for horticulture within the Wellington region by crop type

(Source: Statistics New Zealand & New Zealand Winegrowers Vineyard Surveys)

Crop type	2002	2003	2007	2009	% change
Orchard crops	850	-	545	-	-36
Vegetable crops	448	-	82	-	-82
Other (including flowers)	117	-	193	-	65
Vineyards	-	595	-	859	44
Total*	2,010	-	1,679	-	-16

* Total area of horticulture, which includes orchard crops, vegetable crop, other and vineyards

Based on Greater Wellington's soil stability surveys, in 2002, 1.0% of the region's land area (8,120 ha) was used for cropping and horticulture. This increased to 1.4% of the region's land area (11,380 ha) being used for cropping and horticulture in 2010. The largest changes from 2002 to 2010 were an increase in green-feed crops by 0.3% of the region's area, and an increase in orchards and vineyards by 0.2% of the region's area (Figure 3.9). During the same time period, grain crops decreased by 0.1% of the region's land area, and the change in area of vegetable crops were less than 0.1%.

[7] Data in Crippens and Hicks (2011) suggest horticulture actually increased by 0.4% between 2002 and 2010 – see Sorensen (2012).

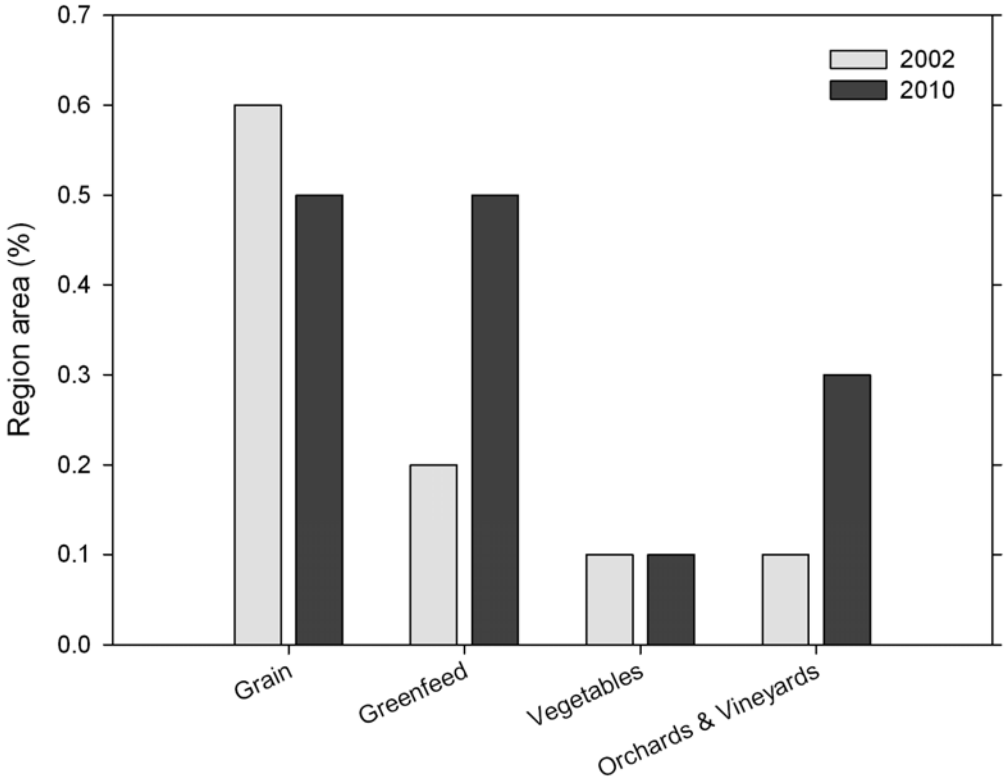
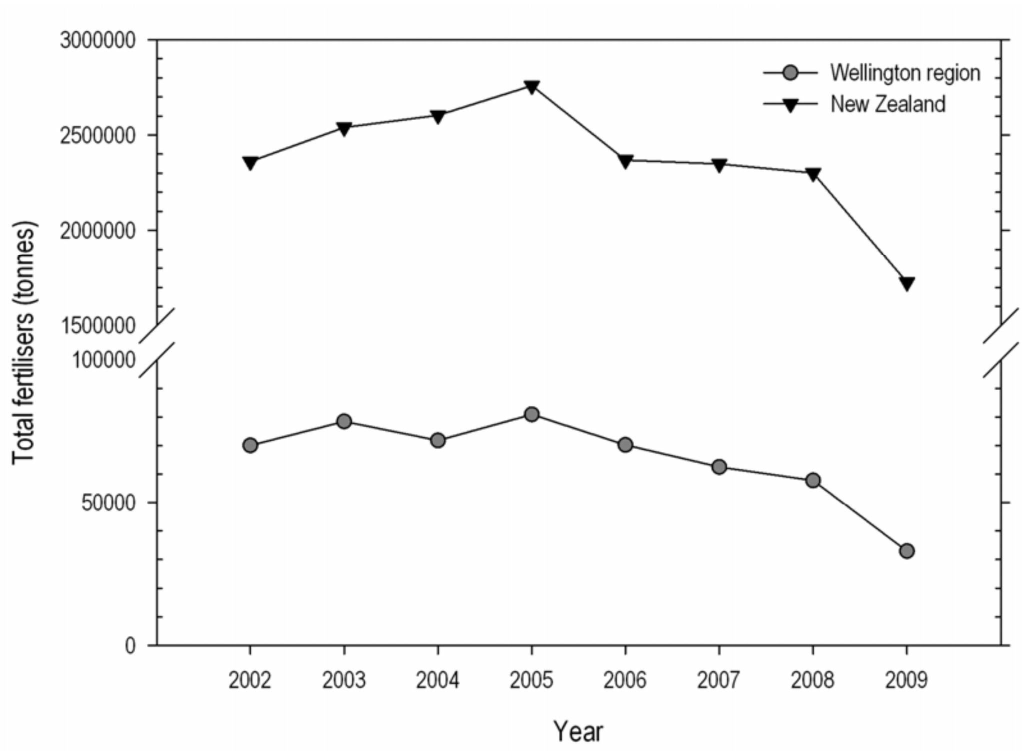


Figure 3.9: Crop types grown within the Wellington region at 2002 and 2010 (from Crippen & Hicks 2011)

3.3.3 Fertiliser usage

Most New Zealand soils, including soils in the Wellington region, are not naturally productive. They tend to be thin and slightly acidic, with low levels of nutrients such as nitrogen, phosphorus and sulphur. To increase the productivity of soils, fertilisers and lime are applied to the land. Historically, superphosphate was the fertiliser of choice, but with increased intensification in land use and higher demands for production in more recent times, farmers have used nitrogen to supplement nitrogen-producing legumes, such as clover (Fert Research 2009).

Information on the volumes of different fertiliser types used throughout the region is difficult to obtain. However, by comparing the trends of total fertiliser usage for the region with that across all of New Zealand, assumptions can be made about how much fertiliser is being applied to the land and in what kind of volumes. Figure 3.10 shows a steady decrease in the total amount of fertilisers applied to land in the Wellington region since 2005, closely mirroring the national trend. In 2009, New Zealand’s phosphate consumption was at an 18-year low, nitrogen usage declined to a 7-year low and the use of potassium fertilisers was at its lowest level in 17 years (Fert Research 2009). Because the Wellington region has closely followed the national trend in total fertiliser usage since 2002, it is likely that the region has similar patterns to those being exhibited nationally with regard to the use of specific fertilisers.



(Source: Statistics New Zealand)

Figure 3.10: Total fertiliser usage between 2002 and 2009 for the Wellington region and across all of New Zealand

The total amount of fertilisers applied to land in the Wellington region has steadily decreased since 2005, mirroring the trend for New Zealand. In 2009, New Zealand's phosphate consumption was at an 18-year low, nitrogen usage declined to a 7-year low and the use of potassium fertilisers was at its lowest level in 17 years (Fert Research 2009). Because the Wellington region has followed a very similar trend in total fertiliser usage to New Zealand since 2002, it is likely that the region has similar patterns to New Zealand with regard to the use of specific fertilisers.

In addition to artificial fertilisers, it has become common practice to apply animal effluent to land as effluent is a good source of nutrients. Anecdotal evidence suggests that the number of hectares of land on which dairyshed effluent is applied has increased over the last 10 years, probably partly in response to dairy intensification as well as concerted efforts to eliminate discharges of dairyshed effluent to water.[8] There are also several resource consents exercised in the region allowing other types of effluent, such as pig and poultry effluent, to be applied to land. See Tidswell et al. (2012) for more information on agricultural effluent discharges to land in the Wellington region.

8 According to Milne and Perrie (2005), there were 63 consented discharges of dairyshed effluent to water in the Wellington region in 1995 – this had dropped to just three by December 2004.

4. Soil quality and stability – state

This section looks at the current state of soil quality at selected monitoring sites across the Wellington region, as well as land stability and soil disturbance throughout the region. It begins by assessing the state of soil quality for each of the land uses monitored, and then examines the effects of the different land uses on each of the soil quality indicators.

The second part of this section reports on the stability of soils in the Wellington region based on the interpretation of aerial photographs (2010) for a number of points across the region. An assessment is made of how much of the region's soil is intact or disturbed, whether or not the disturbance is natural or influenced by land use, and how much of the region's land is covered with bare soil.

4.1 Soil quality

4.1.1 Approach to analysis

The state of soil quality was assessed through examining the results of the most recent soil sampling across each land use. Table 4.1 outlines how many sites have been sampled across each land use type and the year(s) in which each land use was last sampled. Figure 4.1 shows the location of each of the sampling sites by land use type.

The soil quality assessment focused primarily on a comparison of the results of each of seven key soil quality indicators (as outlined in Section 2.1.5) with their respective target range or critical values: bulk density, macroporosity, total carbon, total nitrogen, anaerobic mineralisable nitrogen (AMN), soil pH and Olsen P. In addition aggregate stability (vegetable growing sites only) and trace element results (arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), nickel (Ni) and zinc (Zn)) were also examined.

Table 4.1: Summary of soil quality monitoring sites used to determine the current state of soil quality in the Wellington region, including the number of sites for each land use type and the year each land use was last monitored

Land use	Number of sites (total =108) [9]	Year last sampled
Cropping	7	2010
Dairy	23	2009
Drystock	23	2008
Exotic forest	8	2003
Horticulture	15	2000–04
Vegetable growing	15	2010
Native forest	17	2000–04

[9] Although there are 118 monitoring sites in total, data were only available for 108 sites. Therefore, the state of soil quality is assessed from the results of those 108 sites.

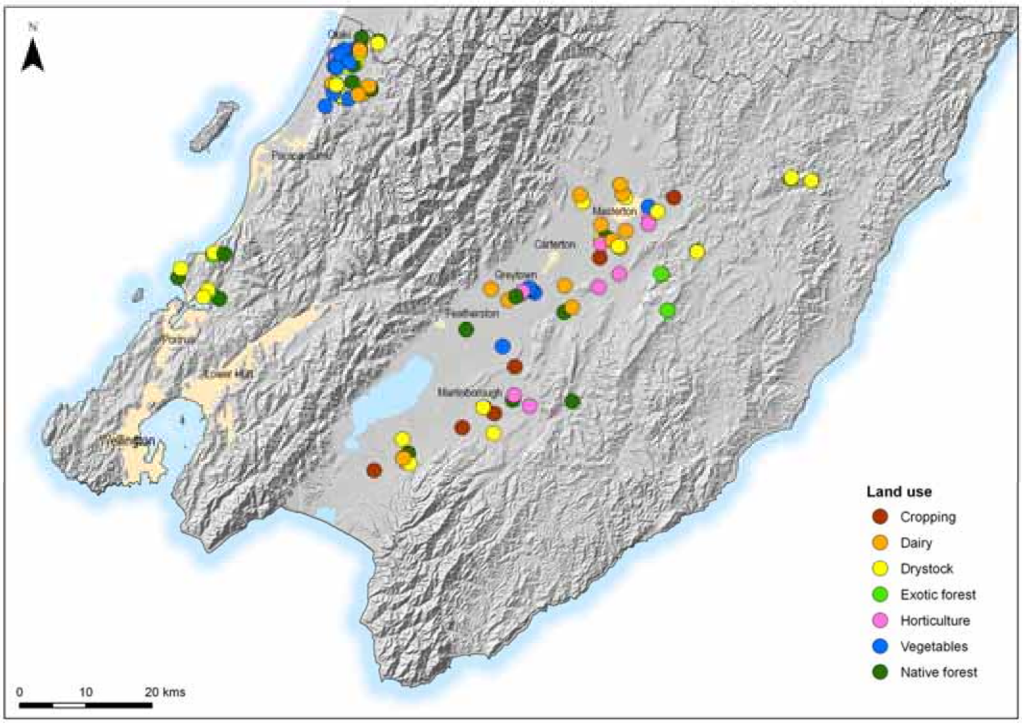


Figure 4.1: Soil quality monitoring sites used to assess the current state of soil quality in the Wellington region

Each indicator has a corresponding target range or critical value (often dependent on land use and/or Soil Order) that was developed by New Zealand experts in soil science (see Section 2.1.6 and Appendix 4). These values provide a way of assessing the results of the soil samples for various soil orders and land uses, and help determine the overall quality of the soil. The native forest sites don't have target range values but soil sampling results from these sites provide useful background information on soils that have not been impacted by land use.

To assess the effects of individual land uses on soil quality, the 108 sites were divided into land use types and assessed against the relevant target range levels for each of the seven soil quality indicators. As shown in Table 4.1, the 108 sites analysed were broken down as follows: cropping (7), dairying (23), drystock (23), exotic forestry (8), horticulture (15), vegetable growing (15) and native forest (17).

Throughout this section soil quality sampling results are summarised using box-and-whisker plots (box plots) and regional maps. The box plots provide comparisons of soil quality results between different land use types. An example of a box-plot is presented in Figure 4.2. The regional maps present the value of a particular soil quality indicator at each monitoring site proportionally (relative to its concentration), with the value colour-coded to show if the value falls within or outside of the target range for that indicator.

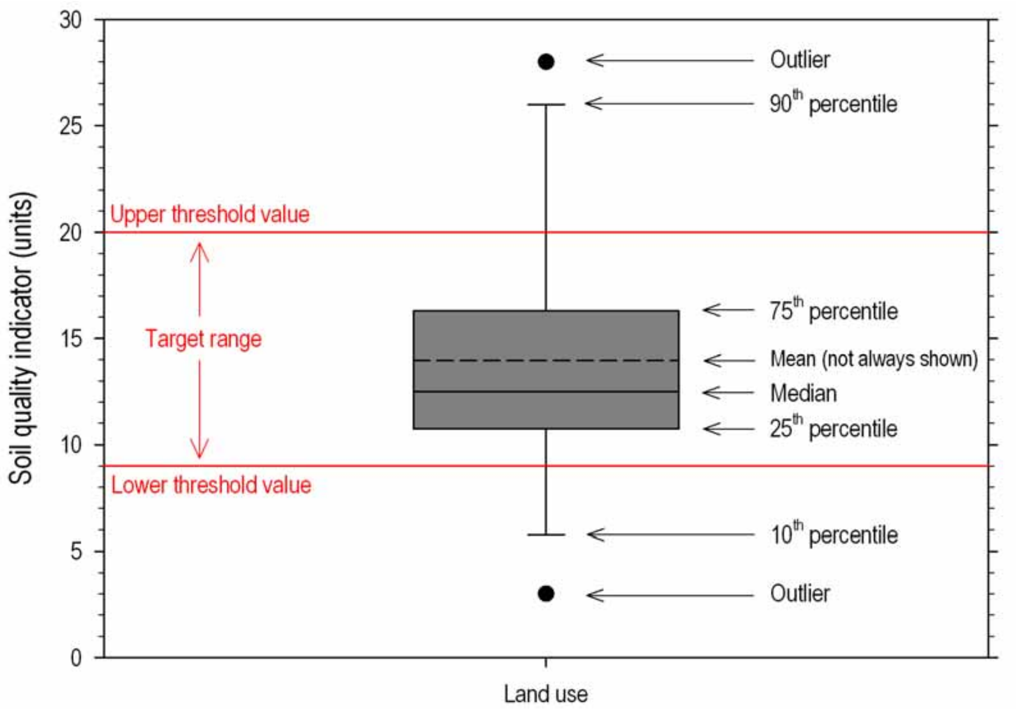


Figure 4.2: An example of a box plot showing the various statistical values

4.1.2 Results

The majority of the soil quality monitoring sites were found to be in good condition when sample results were compared against the relevant target range or critical values. Out of the 108 sites, 42 (38.9%) met all of the soil quality criteria, and a further 46 sites (42.6%) had just one soil quality indicator outside the target (optimal) range. However, soil samples from 20 sites (18.5%) had two or more soil quality indicators outside the target range; most of these soil samples were from vegetable growing, dairying or drystock sites (Figure 4.3).

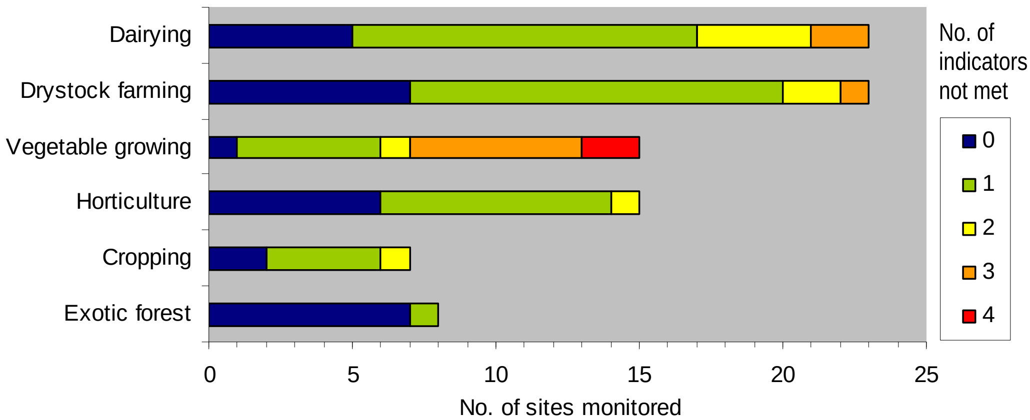


Figure 4.3: Summary of compliance with target range values for seven key soil quality indicators (bulk density, macroporosity, total carbon, total nitrogen, anaerobic mineralisable nitrogen, soil pH and Olsen P), based on the most recent round of soil quality monitoring across different land uses

Note: There are no target range values for native forest soils.

A summary of the soil quality monitoring results by land use type is presented in Table 4.2. Figure 4.4 illustrates the land uses having the most impact on soil quality while also showing where the sites are located within the region.

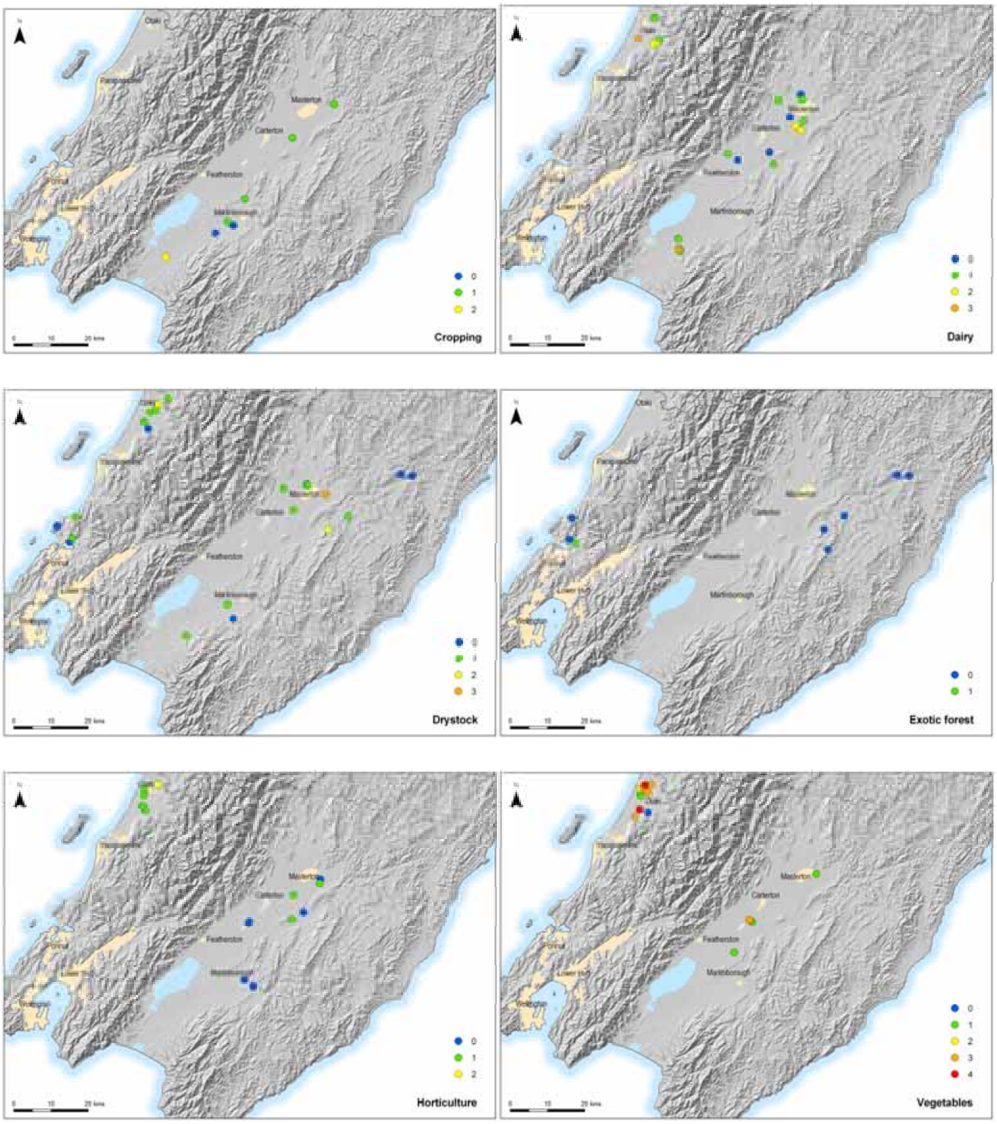


Figure 4.4: Soil quality monitoring sites for each land use (clockwise from top left): cropping (2010), dairy (2009), drystock (2008), exotic forest (2003), horticulture (2000-04) and vegetable growing (2010), colour-coded according to the number of soil quality indicators outside their target range for each site's respective land use and soil type

Apart from the native forest soil results, which can not be compared to target range values, the exotic forest sites had the best soil quality – soil samples from only one site were outside the target range (and for just one soil quality indicator). However, only eight exotic forest sites sampled, which is generally fewer compared to the other land uses, and impacts from forestry is often limited to the time of harvest (especially if clear cutting).

Table 4.2: Summary of the most recent (see Table 4.1 for dates) chemical and physical results for 108 soil quality monitoring sites in the Wellington region categorised according to land use

		Cropping (7 sites)	Dairying (23 sites)	Drystock (23 sites)	Exotic forest (8 sites)	Horticulture (15 sites)	Vegetables (15 sites)	Native forest (17 sites)
Bulk density (Mg/m^3)	Median	1.24	1.05	1.15	1.06	1.16	1.36	0.89
	Range	1.14 – 1.38	0.75 – 1.48	0.77 – 1.33	0.88 – 1.36	0.83 – 1.36	1.06 – 1.65	0.58 – 1.35
	No. sites outside TR	–	1 (4%)	–	–	–	4 (27%)	n/a
Macroporosity (@-10kPa, %)	Median	6.23	9.20	13.73	20.65	12.93	12.47	16.77
	Range	2.20 – 14.13	2.80 – 22.70	4.67 – 25.43	13.83 – 34.87	7.07 – 22.33	1.93 – 21.23	7.87 – 32.90
	No. sites outside TR	5 (71%)	13 (57%)	8 (35%)	-	3	6 (40%)	n/a
Total carbon (% w/w)	Median	3.00	6.03	4.77	5.32	4.16	1.84	6.41
	Range	2.82 – 6.04	4.15 – 11.46	3.34 – 11.00	2.76 – 9.40	2.41 – 8.98	1.23 – 4.66	4.71 – 17.03
	No. sites outside TR	–	–	–	–	–	10 (67%)	n/a
Total nitrogen (% w/w)	Median	0.29	0.54	0.44	0.34	0.32	0.17	0.48
	Range	0.27 – 0.53	0.38 – 0.95	0.29 – 0.87	0.17 – 0.54	0.19 – 0.72	0.12 – 0.39	0.34 – 1.24
	No. sites outside TR	–	7 (30%)	4 (17%)	–	–	–	n/a
C:N* (ratio)	Median	10.17	10.67	10.97	15.51	12.11	10.80	12.96
	Range	9.77 – 11.33	9.49 – 12.11	9.73 – 12.64	11.17 – 18.93	10.24 – 13.30	9.47 – 14.29	11.27 – 17.67
	No. sites outside TR	n/a	n/a	n/a	n/a	n/a	n/a	n/a
AMN (mg/kg)	Median	66	193	138	68	91	39	126
	Range	51 – 226	126 – 288	83 - 257	42 – 118	55– 175	13 – 146	53 – 334
	No. sites outside TR	1 (14%)	3 (13%)	1 (4%)	–	–	3 (20%)	n/a
Soil pH	Median	6.03	5.98	5.92	5.36	6.26	6.24	5.85
	Range	5.59 – 6.12	5.45 – 6.55	5.14 – 6.94	4.57 – 6.11	5.42 – 6.86	5.18 – 7.33	4.82 – 6.34
	No. sites outside TR	–	–	1 (4%)	–	–	–	n/a
Olsen P (mg/kg)	Median	40	68	31	11	33	139	21
	Range	30 – 82	23 – 114	9 – 117	3 – 34	3 – 159	14 - 241	5 – 92
	No. sites outside TR	–	2 (9%)	6 (26%)	1 (13%)	7	10 (67%)	n/a

*Carbon:nitrogen ratio does not have a target range, but is a useful measure to assist with interpreting soil quality results.

n/a: = Not applicable.

The worst soil sampling results were from the 15 vegetable growing sites; samples from nine of these sites had values outside the target range for two or more soil quality indicators, while samples from three drystock and six dairying sites also had values outside the target range for two or more soil quality indicators (Figure 4.4).

Land management practices can vary according to the land use. For example, cultivation occurs frequently on cropping and vegetable growing sites, but infrequently on land used for dairy or drystock farming. Therefore, the impacts on soil quality and individual soil quality indicators can differ greatly depending on the land use. This is demonstrated in Figure 4.5 which shows that dairying, drystock and vegetable growing have had an impact on the greatest number of soil quality indicators.

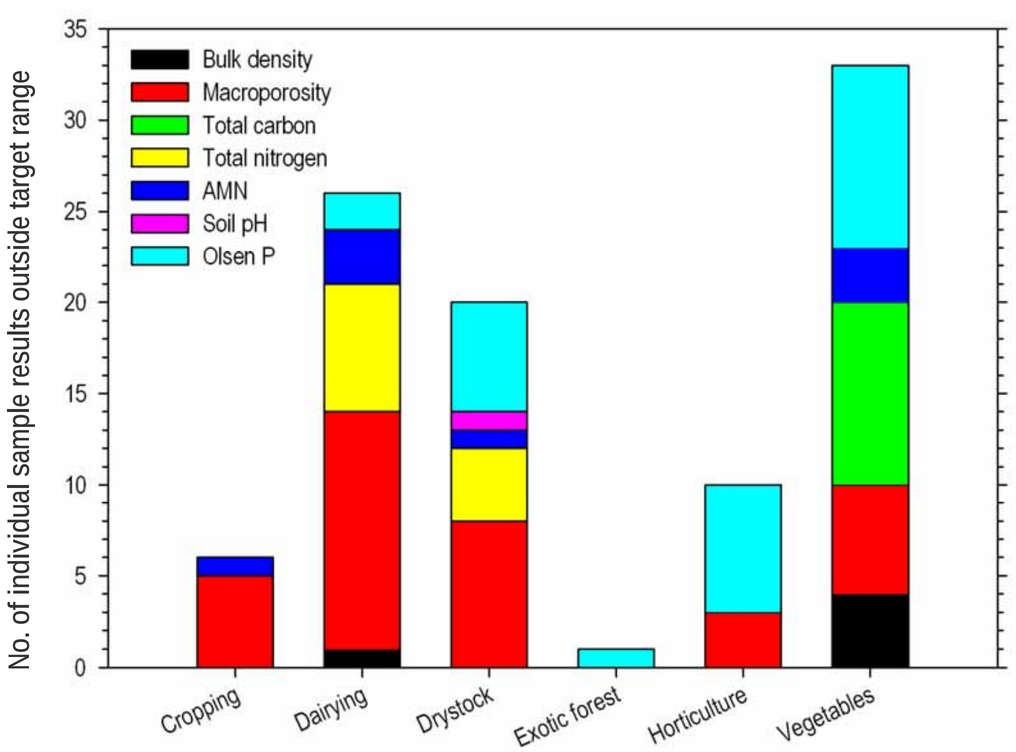


Figure 4.5: Breakdown of soil quality monitoring sites with one or more soil quality indicators outside of the target range, grouped according to land use type

Sampling results from dairying and drystock sites were fairly similar; the soil quality indicators outside of target ranges were most frequently macroporosity, total nitrogen, anaerobic mineralisable nitrogen (AMN) and Olsen P. In total more vegetable growing sites had soil sample results outside target ranges, but compared to the dairying and drystock sites the reason was predominantly for different soil quality indicators: bulk density, macroporosity, total carbon, AMN and Olsen P (Figure 4.5).

Dairying and drystock were the only land uses which had soil sample results outside the target range for total nitrogen, while vegetable growing was the only land use with soil sample results outside the target range for total carbon. Across all of the land uses, macroporosity and Olsen P were the most common soil quality indicators to fall outside of their target ranges (Figure 4.5).

(a) Physical quality

The physical quality of soil is monitored through the indicators bulk density, macroporosity and also aggregate stability for the vegetable growing sites only (refer to Section 2.1.5).

Bulk density across all the sites sampled was generally within the target range level, with the exception of vegetable growing sites (Figure 4.6). The median bulk density values ranged from 1.05 Mg/m^3 at the dairying sites to 1.36 Mg/m^3 at the vegetable growing sites, compared to 0.89 Mg/m^3 at the native forest (background) sites. The cropping sites also recorded relatively high bulk density values. This indicates that the cultivation practices and machinery use at these vegetable growing and cropping sites may be the cause of higher bulk density values, and compaction of these soils. The native forest sites have not been impacted by machinery, cultivation or treading from livestock and have significantly lower bulk density values than all the other land uses.

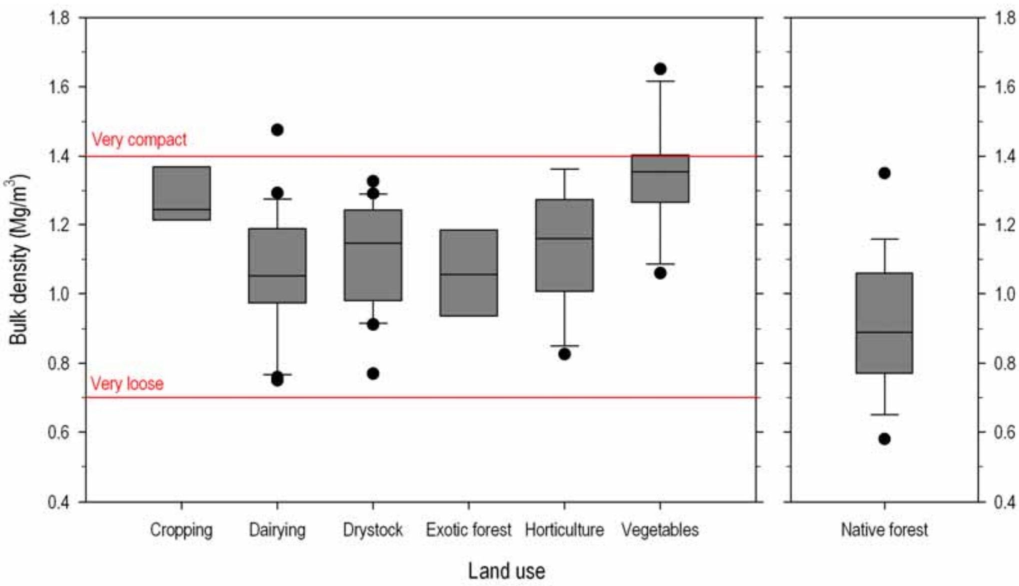


Figure 4.6: Box plot summarising bulk density measured in soil samples taken during the most recent round of soil quality monitoring for each land use. The area between the red lines represents the target range.

Overall, soil samples from five sites recorded high bulk density values (indicating compaction); three from the Wairarapa and two from near Otaki (Figure 4.7).

Macroporosity values were more variable across the different land use types, with most land uses containing a wide range of values (Figure 4.8). All land uses, with the exception of exotic and native forest, had sites with values less than the lower limit of the target range, indicating compaction. This highlights that some land uses and particular land management practices are highly susceptible to causing soil compaction.

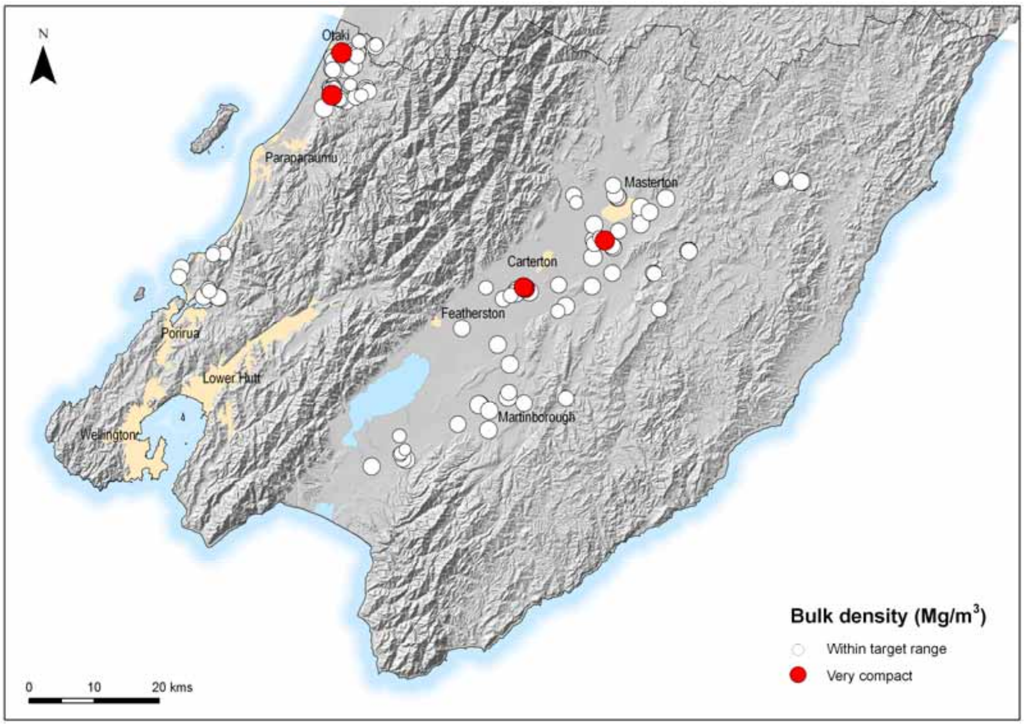


Figure 4.7: Bulk density at each soil quality monitoring site during the most recent round of soil sampling. Circles are proportional in size and colour coded to show which sites had concentrations that were within the target range or very compact.

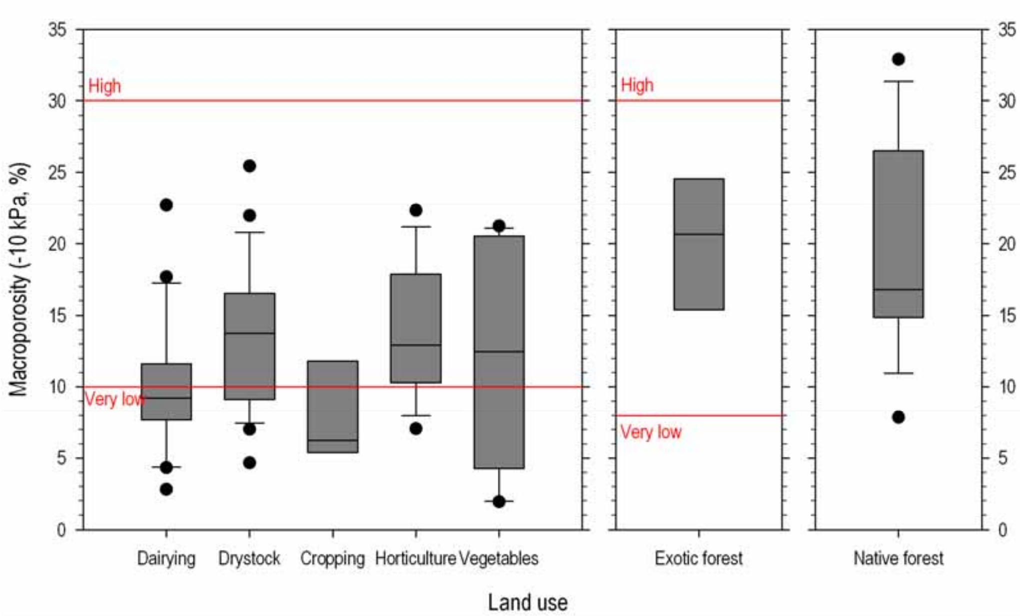


Figure 4.8: Box plot summarising macroporosity values measured in soil samples taken during the most recent round of soil quality monitoring for each land use. The area between the red lines represents the target range.

Exotic forest and native forest soils recorded the highest median macroporosity values of 20.7% and 16.8%, respectively, indicating adequate macropores in the soil. The lowest median macroporosity values were found at the cropping sites (6.2%) and the dairying sites (9.2%), indicating low macropores in the soil due to compaction (although just seven cropping sites were sampled). While vegetable growing sites had a similar median macroporosity value to the drystock and horticultural sites, they had a much larger range, with soil samples from some sites recording very low macroporosity values.

Figure 4.9 shows the macroporosity results for all of the sites throughout the region. The sites with low macroporosity values were evenly split between Otaki and the Wairarapa Valley – however, the Otaki sites are predominantly vegetable growing sites, while the Wairarapa sites are used mainly for dairy farming, drystock farming or cropping.

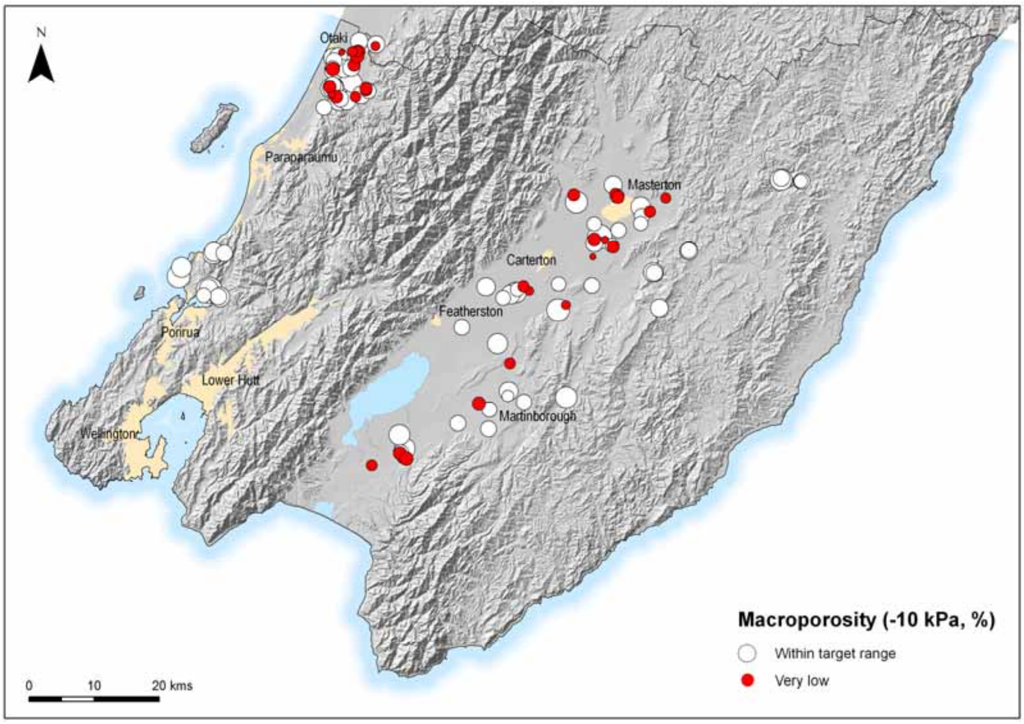


Figure 4.9: Macroporosity at each soil quality monitoring site during the most recent round of soil sampling. Circles are proportional in size and colour coded to show which sites had concentrations that were within the target range or very low.

Aggregate stability was analysed in soil samples from seven of the 15 vegetable growing sites during the most recent sampling round. The results show that aggregate stability was low to very low across all of these sites, ranging from 0.27 to 1.19 mean weighted diameter (m.w.d.) (Figure 4.10). All sites had an aggregate stability value of less than 1.5, which is considered the lower limit for a good soil structure and the level at which production begins to decrease (Beare et al. 2005); five of these sites had values less than 0.5, indicating a poor soil structure and considerable structural degradation (Stevenson 2007). Six out of the seven sites are located near Otaki, and the other site is near Masterton.

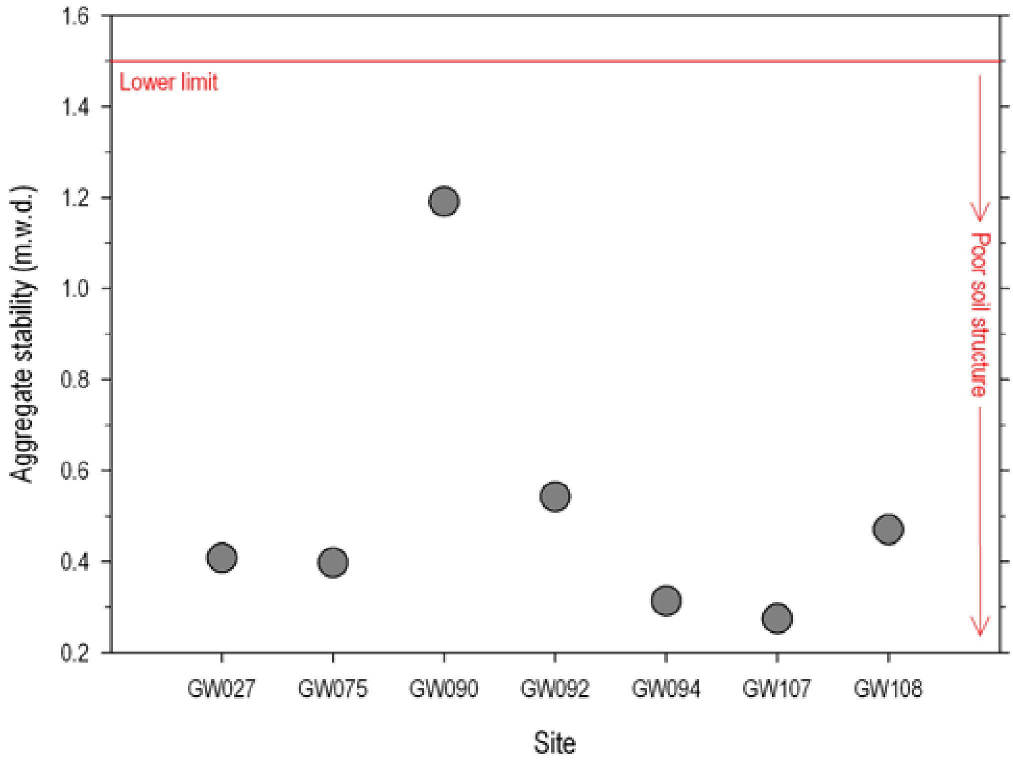


Figure 4.10: Aggregate stability measured at seven vegetable growing sites sampled on one occasion in 2009/10. The red line represents the lower limit for good soil structure, and for sites below this line, indicates production will be impacted.

(b) Organic resources

The organic resources of soil are monitored by the indicators total carbon, total nitrogen and anaerobic mineralisable nitrogen (AMN) (refer Section 2.1.5).

Total carbon values for the most recent soil sampling across each land use are presented in Figure 4.11. Because soil carbon can be affected by soil type the lower threshold value for total carbon is slightly different depending on Soil Order.

The median total carbon value for vegetable growing sites was 1.8% w/w, which is below the lower threshold value of the target range for the soil orders of all sites sampled, and an indication that soils at the majority of the vegetable growing soil sites are very depleted of carbon. Cropping sites soils also had low total carbon with a median value of 3.0% w/w, and a very small range of values compared to the other land uses (possibly due to the small sample size of seven sites). In comparison, the native forest soils had a median value of 6.4% w/w and a much larger range of values, an indication of the higher amounts of organic matter which decompose in native forests. Soil samples from the dairying sites also had a comparatively high total carbon median value of 6.0% w/w.

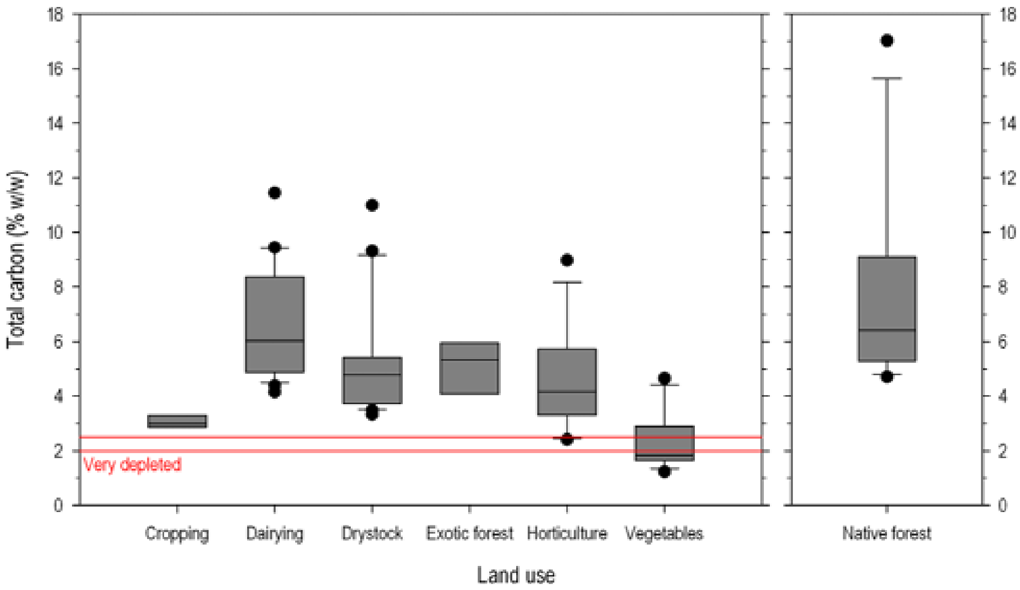


Figure 4.11: Box plot summarising total carbon content measured in soil samples taken during the most recent round of soil quality monitoring for each land use. The red lines represent the lower threshold value*.

* The lower threshold values for total carbon are 2 for Semi-arid, Pumice and Recent soils, and 2.5 for all other Soil Orders

Figure 4.12 shows total carbon values across all of the soil quality monitoring sites throughout the region. As previously mentioned all the sites that are very depleted in terms of soil carbon are vegetable growing sites; seven of these sites are located in the Otaki area and three are located in the Wairarapa.

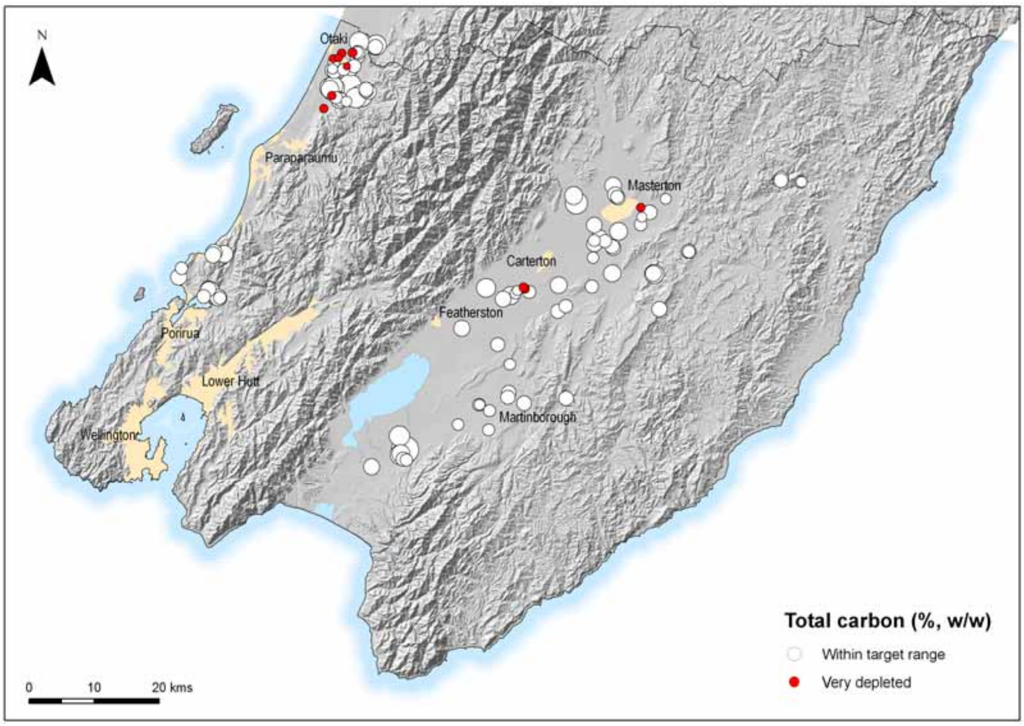


Figure 4.12: Total carbon at each soil quality monitoring site during the most recent round of soil sampling. Circles are proportional in size and colour coded to show which sites had concentrations that were within the target range or very depleted.

Out of all of the land uses with applicable target ranges, soil samples from dairy sites recorded the highest total nitrogen values. The median value for these sites was 0.54% w/w, with seven sites recording total nitrogen values above the upper threshold value of the target range (Figure 4.13). Native forest soils also recorded some high total nitrogen values, which can be attributed to the corresponding high total carbon values for the same sites. High concentrations of nitrogen could increase the risk of nitrogen leaching, but other factors such as the carbon to nitrogen ratio (C:N) and AMN should also be taken into account (Dise et al. (1998); Dise et al. (2009)).

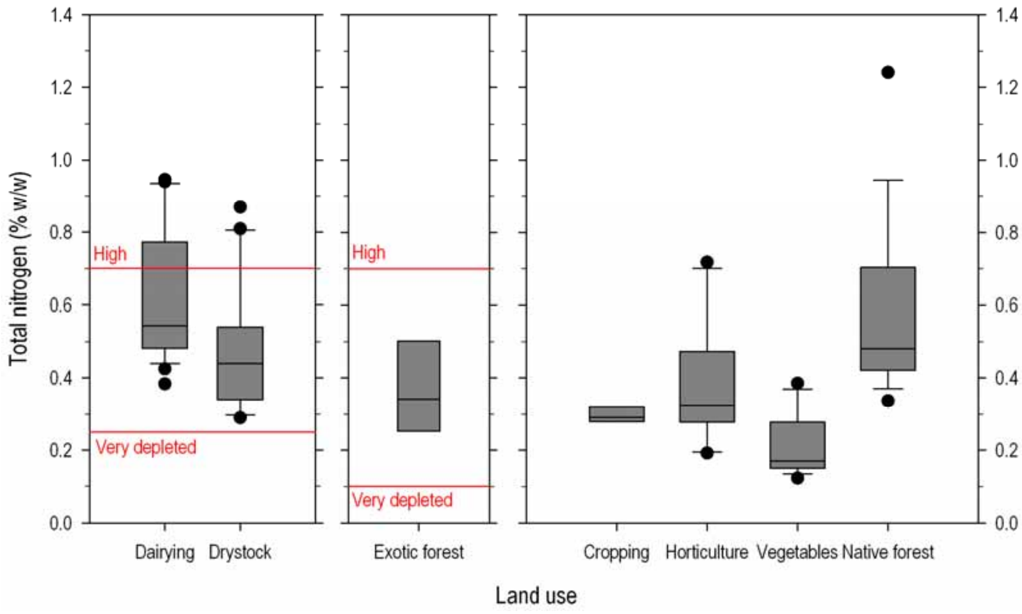


Figure 4.13: Box plot summarising total nitrogen measured in soil samples taken during the most recent round of soil quality monitoring for each land use. The area between the red lines represents the target range*.

* Target ranges for cropping, horticulture and vegetable growing are not specified because target values will depend on the specific crop grown

The lowest total nitrogen values were found in soil samples from vegetable growing sites; the median value for this land use was just 0.17% w/w. Although no lower threshold value is specified for vegetable growing sites (since the value will depend on what crop is grown), total nitrogen values across all the vegetable growing sites were low. The low total nitrogen values can be attributed to the very low total carbon values also found at the vegetable growing sites, which affects the ability of the soil to store nitrogen in the organic form. Similar to the results for total carbon, the range of total nitrogen values for soil samples from the cropping sites was very small compared to the other land uses.

All the soil samples with high total nitrogen values were from either dairying or drystock sites. Five of these sites are located near Otaki and six sites throughout the Wairarapa Valley (Figure 4.14).

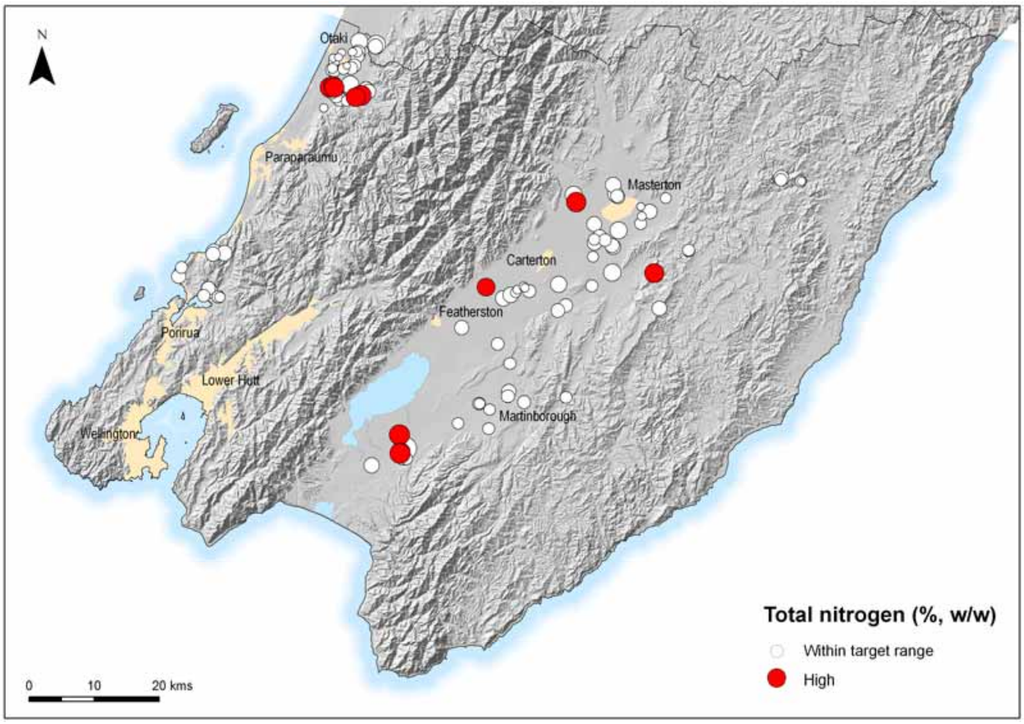


Figure 4.14: Total nitrogen at each soil quality monitoring site during the most recent round of soil sampling. Circles are proportional in size and colour coded to show which sites had concentrations that were within the target range or high.

Anaerobic mineralisable nitrogen (AMN) values varied across all land use types (Figure 4.15). The dairy site soil samples had the highest median value of 193 mg/kg; although this does not exceed the upper threshold value for pasture, it is considerably greater than the median values of soils sampled under other land uses. The land use with the lowest median value is vegetable growing (39 mg/kg), which is not surprising given the low concentrations of total nitrogen and total carbon also found at the vegetable growing sites. The native forest sites contained a wide range of values, ranging from 53 mg/kg to 354 mg/kg.

Given that AMN is used as a surrogate for microbial biomass, the results indicate that soil microbiology is particularly high at the native forest, dairy and drystock sites, but generally low at the vegetable growing sites.

Sites which recorded either excessive or very low concentrations of AMN are spread across the region (Figure 4.16). The three sites with very low amounts (and inferred poor soil biology) are vegetable growing sites located near Otaki, while the sites with excessive AMN concentrations are dairy (3), drystock (1) or cropping (1) sites located both near Otaki and in the Wairarapa.

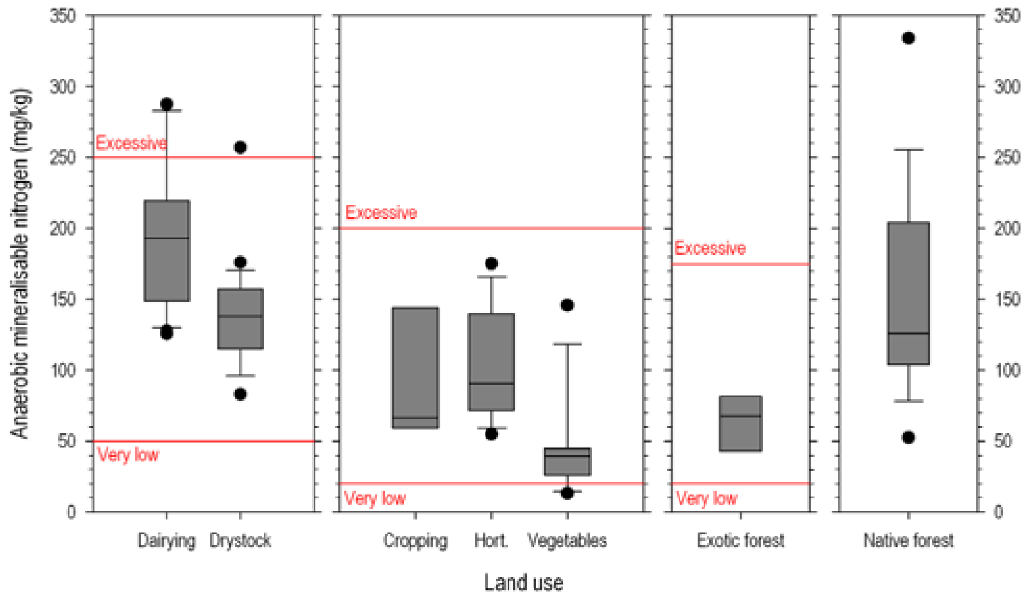


Figure 4.15: Box plot summarising anaerobic mineralisable nitrogen (AMN) concentrations measured in soil samples taken during the most recent round of soil quality monitoring for each land use. The area between the red lines represents the target range.

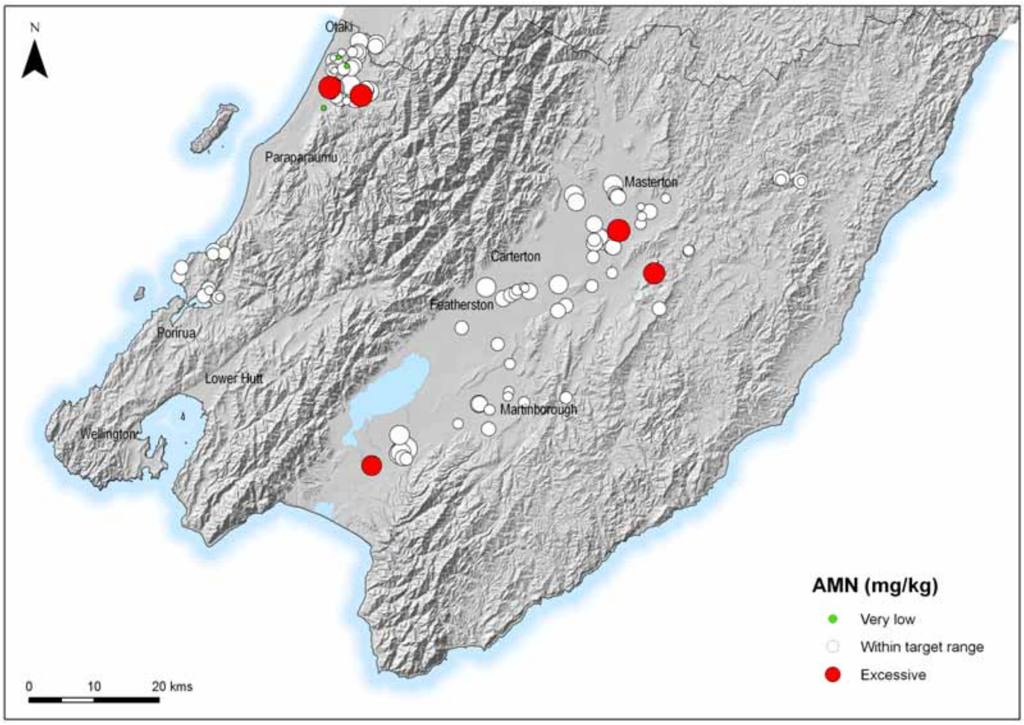


Figure 4.16: Anaerobic mineralisable nitrogen (AMN) at each soil quality monitoring site during the most recent round of soil sampling. Circles are proportional in size and colour coded to show which sites had concentrations that were within the target range, excessive or low.

(c) Acidity

Soil pH values were reasonably consistent, and all but one soil sample (from a drystock farm near Masterton located on limestone-derived soils) across all of the land use types sampled had soil pH values within their respective target ranges (Figure 4.17 and Figure 4.18). Horticulture and vegetable growing soils recorded slightly higher pH values than the other land uses with medians of 6.26 and 6.24, respectively. In contrast, exotic forest soils recorded the lowest soil pH values with a median value of 5.36. Soil pH ranged from 4.82 to 6.34 at the native forest sites.

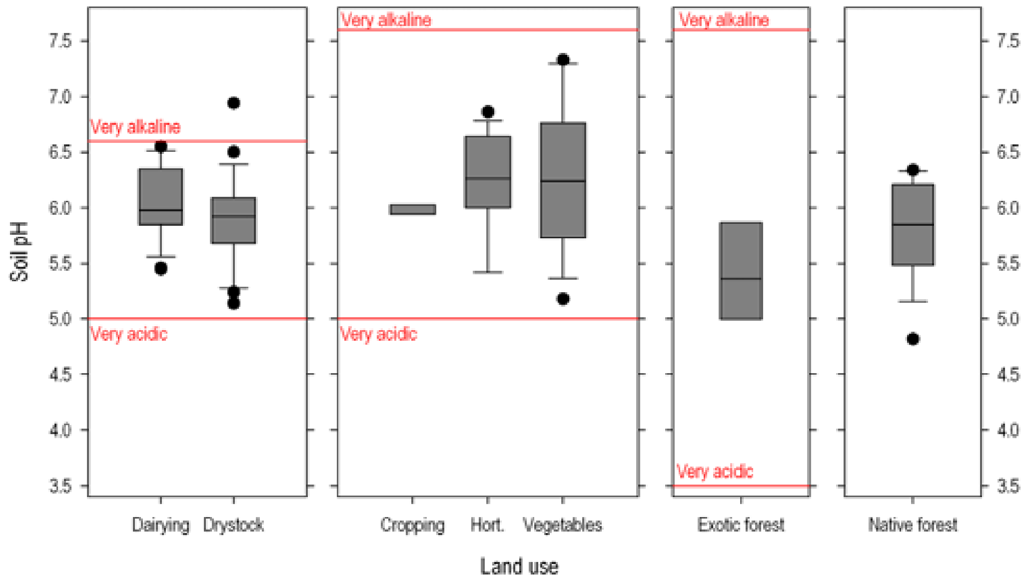


Figure 4.17: Box plot summarising soil pH measured in soil samples taken during the most recent round of soil quality monitoring for each land use. The area between the red lines represents the target range.

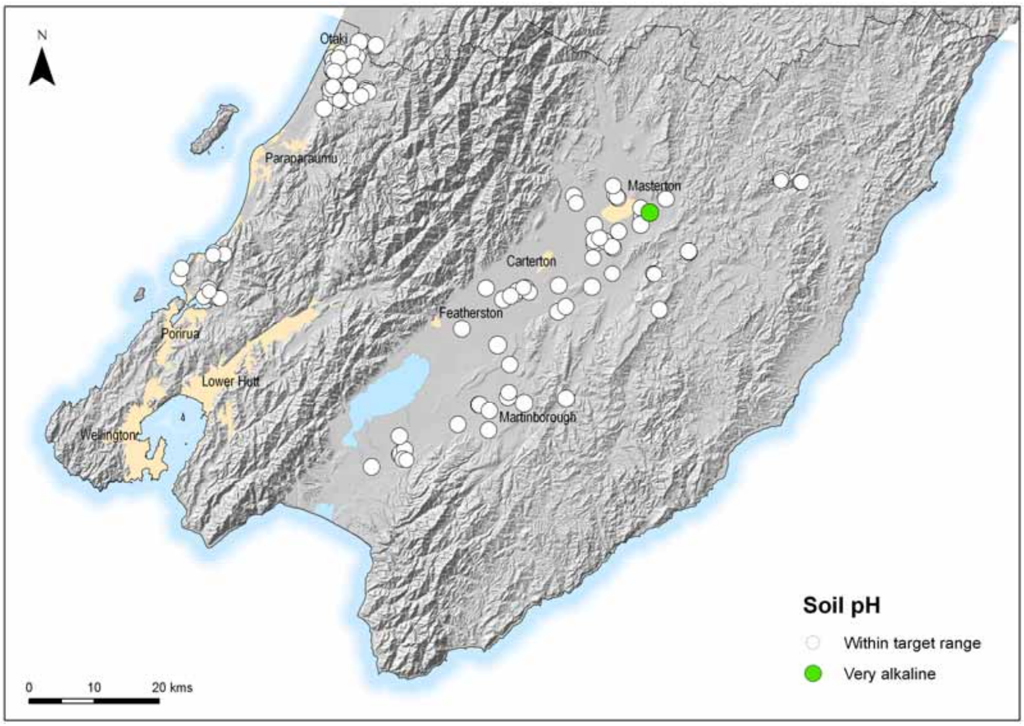


Figure 4.18: Soil pH at each soil quality monitoring site during the most recent round of soil sampling. Circles are proportional in size and colour coded to show which sites had concentrations that were within the target range or very alkaline.

(d) Fertility

Soil Olsen P values for each land use type are presented in Figure 4.19. Vegetable growing soils recorded the highest concentrations of Olsen P, considerably higher than in soils from all other land uses. The median concentration of 139 mg/kg exceeds the upper threshold limit of 100 mg/kg, which is an indication that soil Olsen P concentrations are excessive at the majority of vegetable growing sites, and at levels which could impact on the surrounding environment. Dairy farm soils also recorded high Olsen P concentrations (median 68 mg/kg). A recent review of soil quality target ranges concluded that the upper threshold limit for Olsen P of 100 mg/kg is too high, and could be reduced to 40 mg/kg for pasture, horticulture and cropping on sedimentary soils (Taylor 2011b).

In contrast, exotic forest and native forest sites, which receive minimal if any inputs of additional phosphorus, recorded low median concentrations of Olsen P (11 and 21 mg/kg, respectively). However, when individual sample results were examined, it was noted that soils from four native forest sites recorded relatively high concentrations of Olsen P (greater than 35 mg/kg). All four of these sites are small remnants of native forest surrounded by agricultural land[10]; it is probable that these sites have received additional phosphate fertiliser through fertiliser application drift particularly since the mean Olsen P concentration across the other 13 native forest sites was just 17 mg/kg.

Overall, of the 15 sites that recorded high Olsen P concentrations, 11 are located near Otaki (Figure 4.20), with nine of these being vegetable growing sites. The 11 sites with very low concentrations of Olsen P are located more sparsely throughout the region; four are located near Otaki, three on the hills near Porirua, and the remaining four in the Wairarapa.

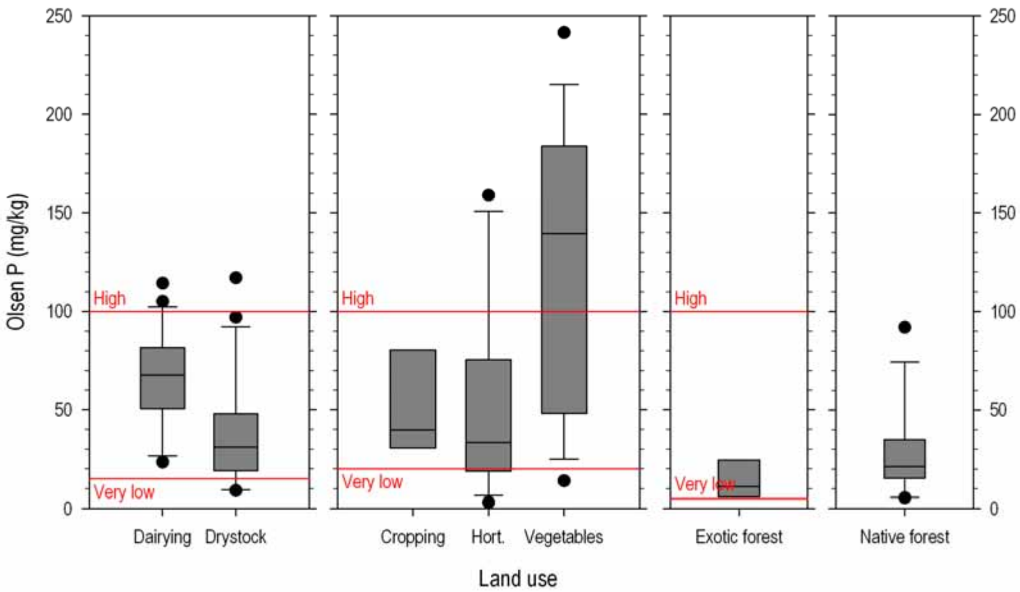


Figure 4.19: Box plot summarising Olsen P concentrations measured in soil samples taken during the most recent round of soil quality monitoring for each land use. The area between the red lines represents the target range.

10 Two sites classified as "native bush" have a land use of urban park or lawn with native trees – therefore soils taken from these sites may not truly reflect those of unmodified native forest.

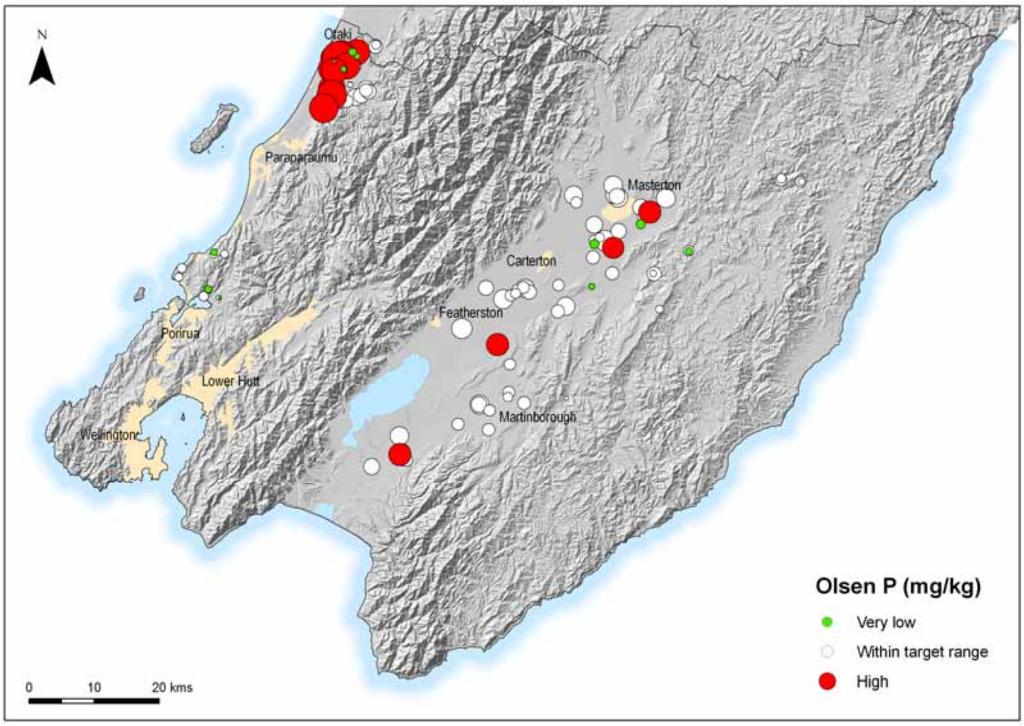


Figure 4.20: Olsen P concentrations measured at each soil quality monitoring site during the most recent round of soil sampling. Circles are proportional in size and colour coded to show which sites had concentrations that were within the target range, very low or high.

(e) Trace elements

With the exception of cadmium, concentrations of the majority of trace element measured in soil samples across all land use types were within typical background concentrations (as represented by the concentrations from the native forest sites). The NZWWA (2003) guideline for arsenic was exceeded in soil samples from two sites, one dairy site and one drystock site (Table 4.3). The source of arsenic at these two sites has not been verified, and further sampling would be required to determine if arsenic concentrations are elevated across the sites.

The highest cadmium concentrations were found in soil samples from dairy farm sites (Figure 4.21)[11]; the median concentration was 0.50 mg/kg and individual values ranged from 0.23 mg/kg to 1.30 mg/kg. Three dairy farm soil samples recorded cadmium concentrations greater than 0.6 mg/kg, which is the ‘a’ trigger value of the Tiered Fertiliser Management System (TFMS) in the New Zealand Cadmium Management Strategy (Ministry of Agriculture and Forestry 2011). One dairy site recorded 1.30 mg/kg of cadmium, which is greater than the ‘b’ trigger value in the TFMS.

11 For sites which had concentrations reported below the laboratory detection limit, a concentration of one half the detection limit was used for the calculation of summary statistics.

Table 4.3: Summary of total recoverable trace element concentrations in soil samples from the most recent round of soil quality monitoring across each land use

		Cropping (*n*=7)	Dairying (*n*=23)	Drystock (*n*=23)	Exotic forest (*n*=8)	Horticulture (*n*=15)	Vegetables (*n*=15)	Native forest (*n*=17)
Arsenic (As) (mg/kg)	Median	3.2	4.0	3.4	4.0	4.5	6.6	3.0
	Min	<2	<2	<2	2.0	2.0	<2	<2
	Max	5.4	30.0	23.0	7.0	9.0	10.5	10.0
	No. sites outside TR	-	1	1	-	-	-	-
Cadmium (Cd) (mg/kg)	Median	0.18	0.50	0.20	0.08	0.20	0.23	0.10
	Min	0.18	0.23	< 0.10	< 0.1	< 0.1	< 0.10	< 0.1
	Max	0.31	1.30	0.60	0.60	0.60	0.36	0.30
	No. sites outside TR	-	1	-	-	-	-	-
Chromium (Cr) (mg/kg)	Median	17.8	17.0	15.0	13.0	13.5	18.0	12.0
	Min	9.2	9.8	7.6	9.0	11.0	4.8	6.0
	Max	20.0	50.0	21.0	16.0	20.0	23.0	16.0
	No. sites outside TR	-	-	-	-	-	-	-
Copper (Cu) (mg/kg)	Median	9.8	13.0	9.8	7.0	19.0	25.0	12.0
	Min	3.5	6.8	3.0	5.0	8.0	4.1	6.0
	Max	16.8	35.0	25.0	8.0	70.0	100.0	22.0
	No. sites outside TR	-	-	-	-	-	-	-
Lead (Pb) (mg/kg)	Median	15.3	16.0	12.0	7.0	10.5	25.0	9.0
	Min	7.8	7.3	6.6	7.0	5.0	6.4	3.0
	Max	20.0	32.0	43.0	12.0	18.0	33.0	15.0
	No. sites outside TR	-	-	-	-	-	-	-
Nickel (Ni) (mg/kg)	Median	15.1	12.0	9.5	9.9	12.0	16.0	14.3
	Min	5.0	4.0	4.4	8.7	9.6	2.1	9.1
	Max	19.2	24.0	21.0	16.2	24.7	22.0	59.0
	No. sites outside TR	-	-	-	-	-	-	-
Zinc (Zn) (mg/kg)	Median	80.0	79.0	58.0	44.5	69.0	84.0	66.0
	Min	28.0	33.0	31.0	29.0	51.0	15.3	40.0
	Max	88.0	120.0	120.0	51.0	100.0	107.0	104.0
	No. sites outside TR	-	-	-	-	-	-	-

TR: Target range

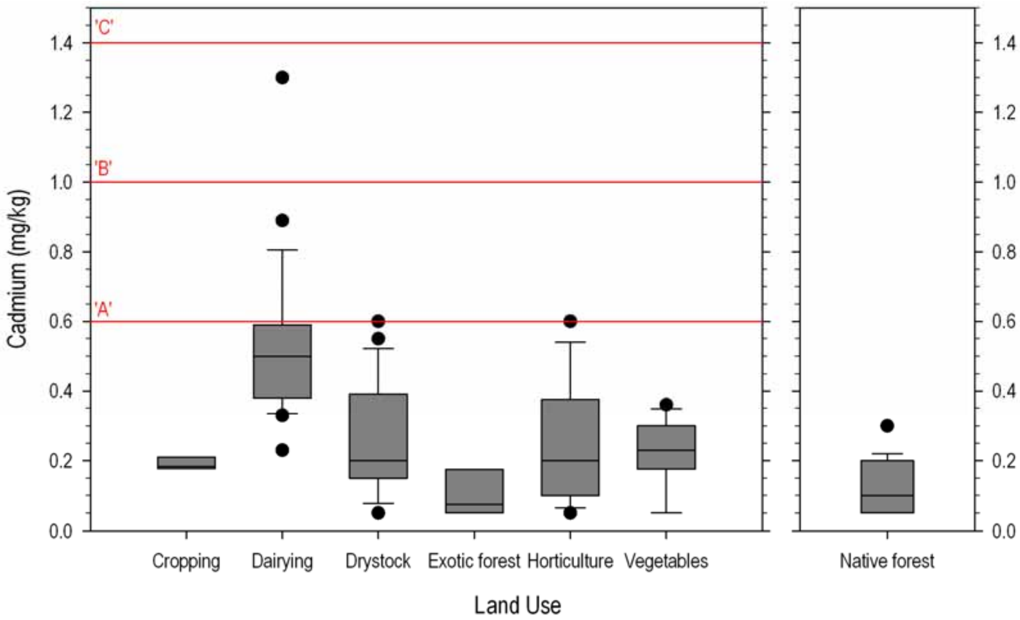


Figure 4.21: Box plot summarising total recoverable cadmium concentrations measured in soil samples taken during the most recent round of soil quality monitoring for each land use. The red lines represent the trigger values of the Tiered Fertiliser Management System (Ministry of Agriculture and Forestry 2011).

Cadmium concentrations in soil samples from the vegetable growing sites were surprisingly low (median 0.27 mg/kg) considering Olsen P concentrations were high at these sites. This is probably because pastoral farming typically uses a phosphate fertiliser that contains a higher concentration of cadmium (probably superphosphate) than vegetable growing sites – diammonium phosphate (DAP) is commonly applied to the latter sites and this generally contains less cadmium.

4.2 Soil stability and conservation cover

The current state of soil stability, disturbance, bare soil and the presence and effectiveness of soil conservation covers is assessed from a point survey analysis of aerial photographs taken in 2010. The soil stability survey is presented in full in Crippen and Hicks (2011) and is summarised in this section.

4.2.1 Soil stability

In 2010, 79% of soil in the Wellington region was located on stable land surfaces (Figure 4.22). Of this, 44% was on stable surfaces that show no signs of past erosion and are completely vegetated (unless topsoil is disturbed by land use). Such land includes drained wetlands, protected floodplains, elevated terraces, rolling down lands and plateaux, foot-slopes, hill country spurs and mountain ranges (Crippen & Hicks 2011). The remaining 35% of soil on stable surfaces was on erosion-prone surfaces which are considered inactive. This is because scars from past erosion have healed and are well vegetated (unless topsoil is disturbed by land use), and any previous erosion has usually occurred at least a decade ago. This land includes healed erosion scars in hill country and mountain ranges, inactive gullies on down lands, terrace edges, flood-prone river flats, un-drained wetlands and stabilised sand dunes (Crippen

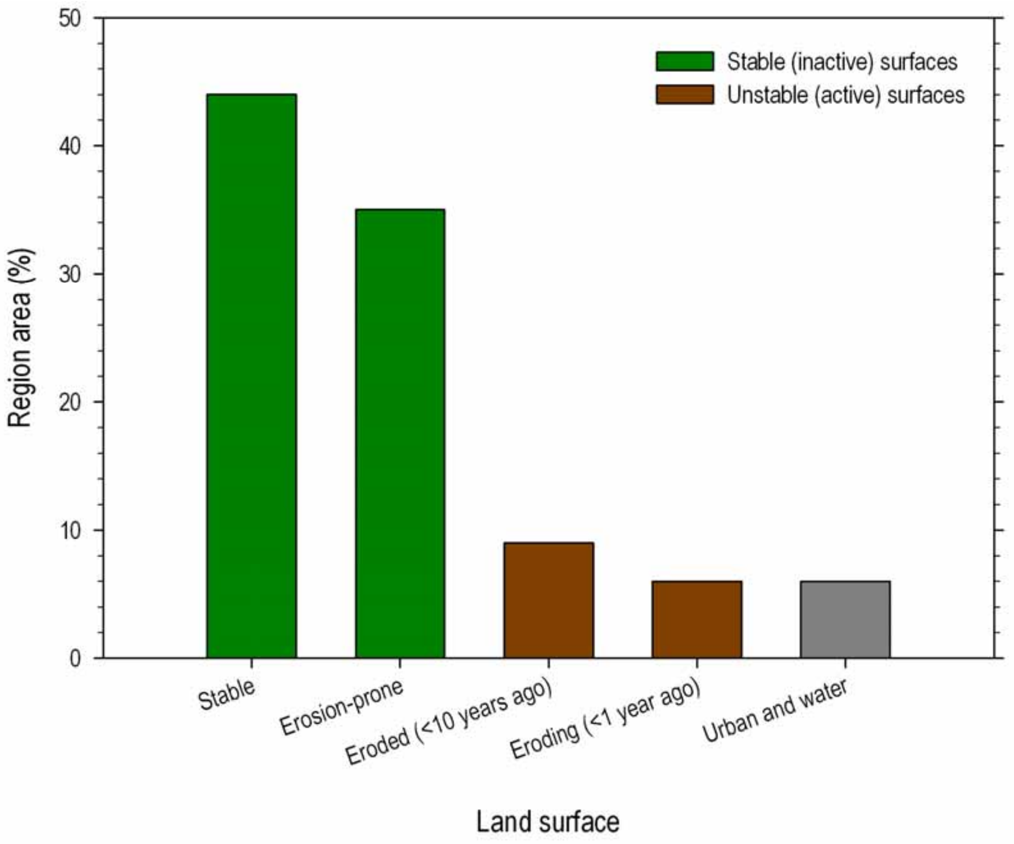


Figure 4.22: Soil stability in the Wellington region as determined from a point survey analysis of aerial photographs taken in 2010 (adapted from Crippen & Hicks 2011)

& Hicks 2011). On this soil, vegetation cover (whether crops, pasture, plantations, scrub or forest) is at present sufficiently dense to protect soil against natural disturbance, but the soils may still be disturbed where vegetation has been removed in the course of land use (Crippen & Hicks 2011).

A further 15% of soil in the Wellington region was located on unstable (active) land surfaces. This land includes mass movement scars, gullies, areas of scour and deposition on stream banks, areas where sand is blown away or accumulates, and miscellaneous disturbances such as rock fall on bluffs, and high altitude sheet or scree erosion (Crippen & Hicks 2011). Of this, 9% of soil is classed as eroded and has been recently disturbed (within 10 years) but is now re-vegetating, and 6% of soil is classed as eroding and has been freshly disturbed within the last year.

The remaining 6% of the soil in the Wellington region was either extensively modified through being covered by urban buildings and parks, rural buildings and infrastructure, roads or was submerged beneath water.

4.2.2 Soil disturbance and bare soil

Related to soil stability, soil disturbance assesses whether soil is currently at risk of removal or re-position, either through natural processes or land use related activities (Burton et al. 2009). The disturbance may reduce the land's on-site productive capability. Off-site it may create environmental pressures, notably if soil enters water bodies. On disturbed surfaces, not all the soil is actually bare. How much is bare, is a measure of the soil at risk of erosion (temporarily exposed by land use) or actually eroding (currently exposed by natural processes) (Crippen & Hicks 2011).

Stable land surfaces can be disturbed by land use activities, while unstable land surfaces are disturbed by natural processes. However, only a small percentage of disturbed soil is actually bare soil. In 2010, 29% of the Wellington region's soil was categorised as being disturbed, 14% disturbed by land use activities, and the remaining 15% disturbed by natural processes (Figure 4.23). Of the 14% disturbed by land use, 9% was on stable surfaces, and 5% on erosion-prone surfaces. Of the 15% of the region's soil disturbed by natural processes 9% was on eroded surfaces, where erosion has taken place within the previous 10 years, and 6% on eroding surfaces, where erosion has taken place within the previous year.

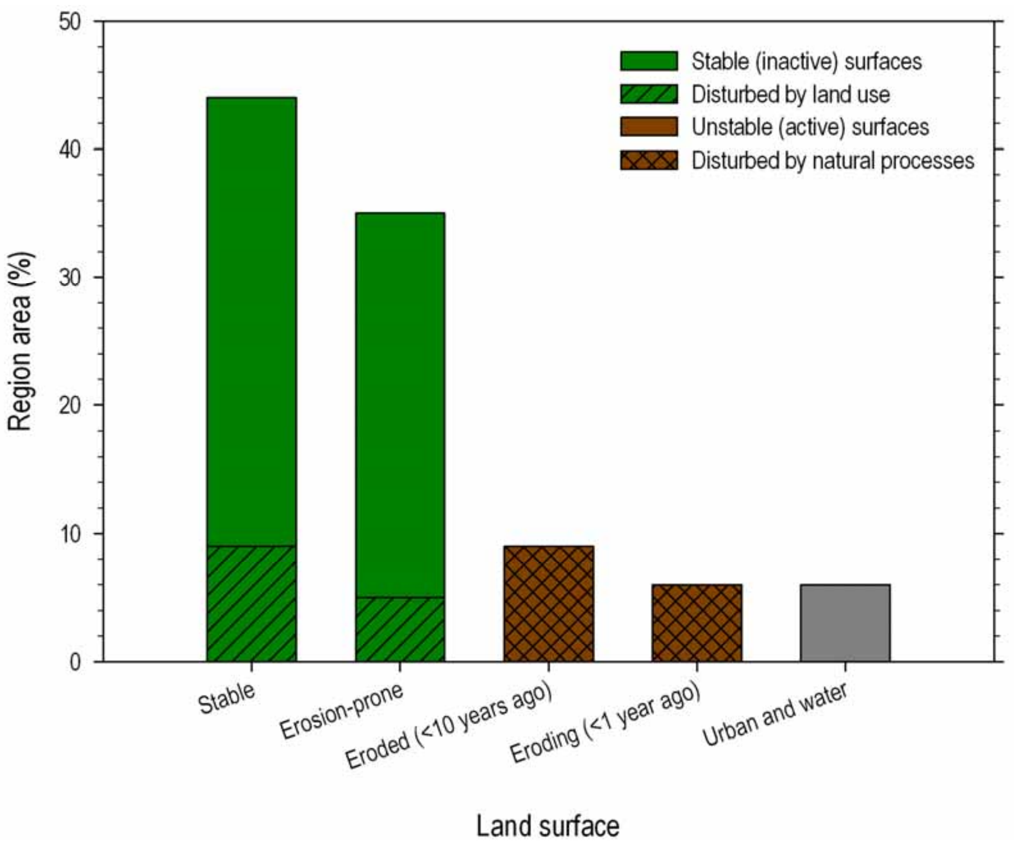


Figure 4.23: Soil disturbance caused by both land use activities and natural processes in the Wellington region as determined from a point survey analysis of aerial photographs taken in 2010 (adapted from Crippen & Hicks 2011)

The land use activity responsible for the majority of soil disturbance across the region was farm and forest tracking, covering 8.3% of the region's area (Figure 4.24a) (although only a very small proportion of land disturbed by farm and forest tracking actually caused bare soil). All the other land use activities were very similar, responsible for disturbing approximately 1% of the region's area, and causing very minimal amounts of bare soil. However, while only a small amount of land was disturbed by cultivation, nearly half of the land disturbed by cultivation was bare soil.

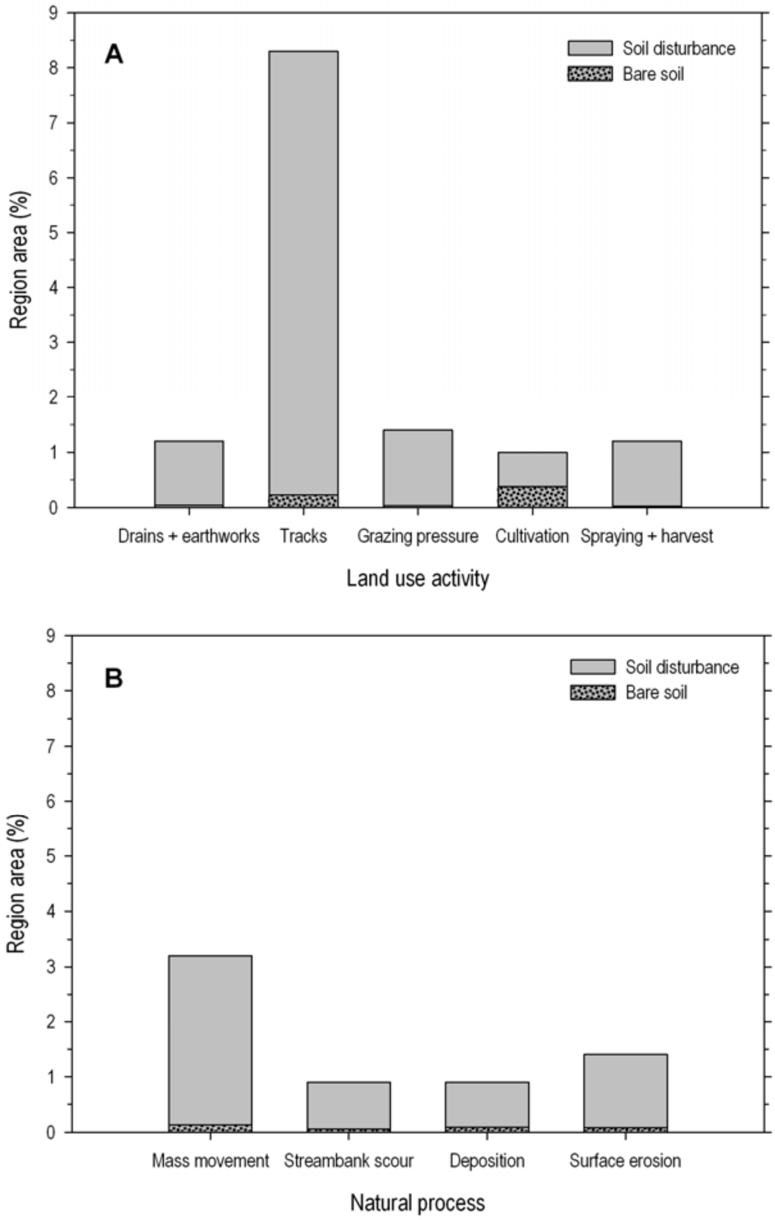


Figure 4.24: Soil disturbance and associated bare soil caused by (a) land use activities and (b) natural processes in the Wellington region as determined from a point survey analysis of aerial photographs taken in 2010 (adapted from Crippen & Hicks 2011)

Figure 4.24b shows the types of disturbance caused by natural processes across the region. Mass movement, including landslides, slumps, earth flows and debris avalanches were responsible for the majority of soil disturbance caused by natural processes (3.2% of the region's soil). This was followed by surface erosion and then gully and stream bank scour, and stream bank deposition. Only very small proportions of land disturbed by all natural processes actually caused bare soil.

Land use activities – and to a lesser degree natural processes – can vary between land uses, given the different landscapes which dominate each land use type. The contribution of each land use type to the total amount of bare soil in the region is presented in Figure 4.25.

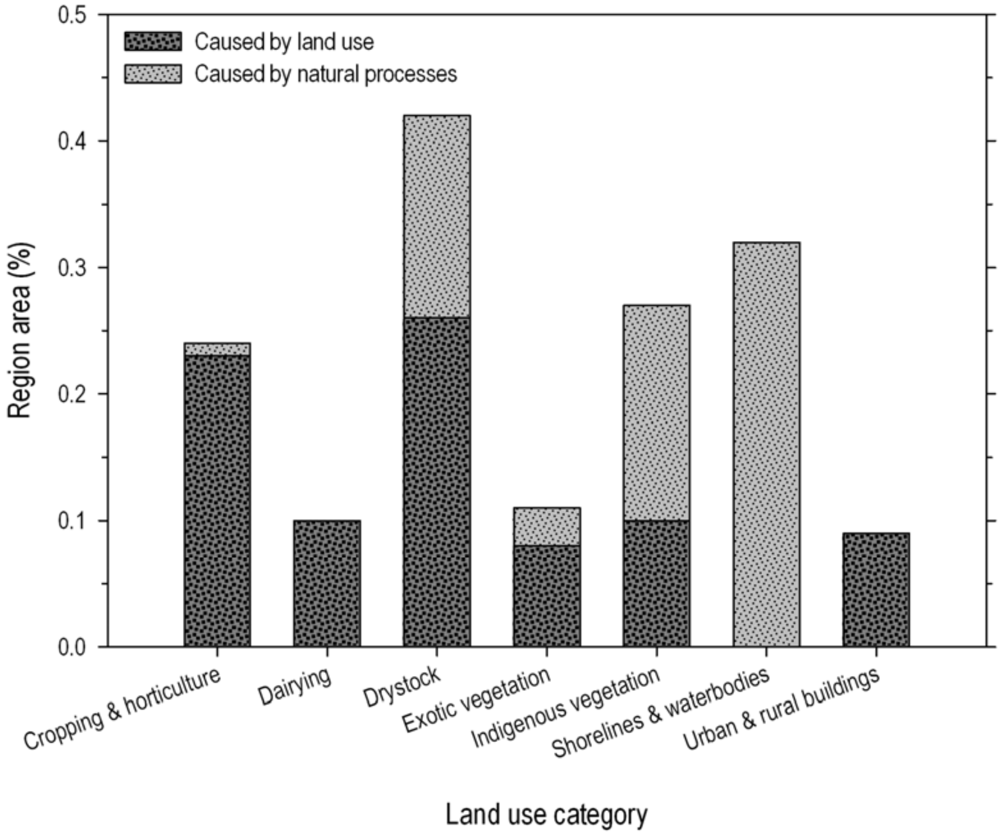


Figure 4.25: Contribution of bare soil (as a percent of the region) by land use in the Wellington region as determined from a point survey analysis of aerial photographs taken in 2010 (adapted from Crippen & Hicks 2011)

In 2010, 1.1% of the Wellington region had bare soil, equivalent to approximately 8,900 ha. Drystock farming was the largest contributor of bare soil out of the different land use types. Bare soil from drystock farming covered 0.42% of the region (equivalent to approximately 3,400 ha), predominantly disturbed by land use activities (0.26%) and natural processes (0.16%). As well as drystock farming, cropping and horticulture, dairying and exotic vegetation exposed bare soil – predominantly through land use activities. In contrast, bare soil was exposed under indigenous vegetation mainly as a result of natural processes.

4.2.3 Soil conservation cover (SCC)

Vegetation cover is an important factor in stabilising soil on erosion-prone surfaces, and is the main means of erosion control advocated by Greater Wellington. However, only certain types of vegetation provide protection from erosion, and although primary vegetation may be present and even dense, it has a limited effect if it is herbaceous (eg, grass, crops, rushes, etc) (Crippen & Hicks 2011). A stabilising effect is usually achieved where secondary woody vegetation (scrub or trees) is present and sufficiently dense to exert various root re-enforcements and de-watering effects (Crippen & Hicks 2011).

Woody vegetation (soil conservation cover) can be present in many forms, including natural vegetation (trees and scrub), residual vegetation (exotic scrub and weeds), forest plantations – or it can be present on farmland. In 2010, 72.8%[12] of the region was classed as requiring some form of vegetative (woody) soil conservation cover (Figure 4.26). The remaining 27.2% of the region, on which soil conservation cover is not required, includes roads and buildings, shorelines and water bodies, and farmland that is low-lying and not susceptible to erosion.

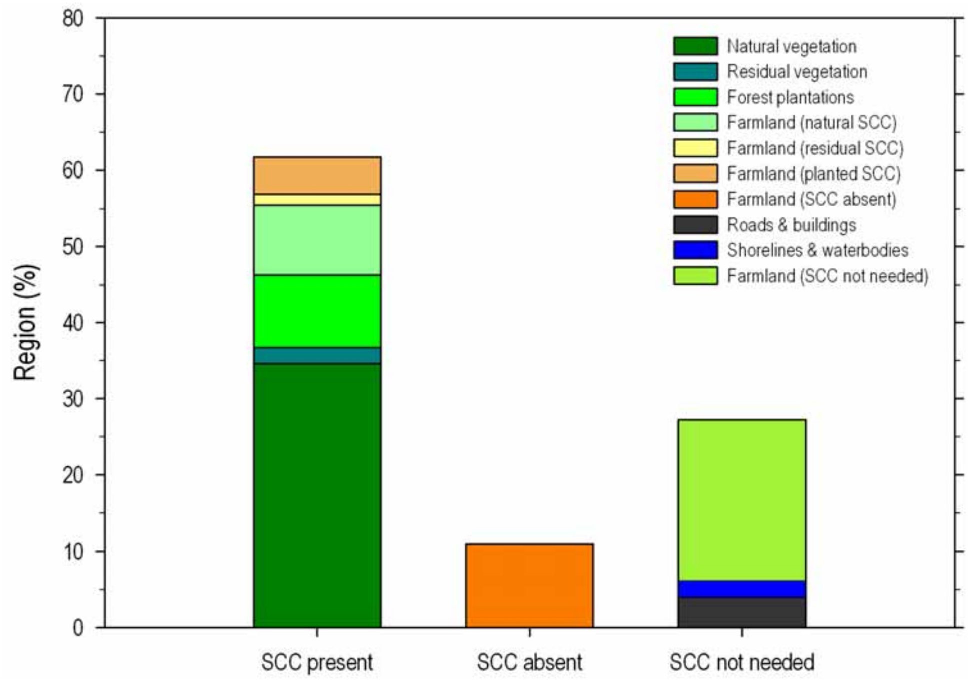


Figure 4.26: Extent of soil conservation cover (SCC) in the Wellington region as determined from a point survey analysis of aerial photographs taken in 2010 (adapted from Crippen & Hicks 2011)

Out of the 72.8% of the region that needs soil conservation cover, 61.7% of that had some kind of woody vegetation to provide protection from erosion. Natural vegetation (mainly trees and scrub) provided the majority (34.6%) of soil conservation cover for the region. Of the 26.4% of farmland requiring soil conservation cover, 58% had some kind of soil conservation cover whether it was natural, residual or planted. This indicates that – as at 2010 – a further 42% (approximately 89,300 ha) of farmland in the region which is susceptible to soil erosion still needs some kind of soil conservation cover.

The amount of bare soil exposed amongst soil conservation covers is a measure of the effectiveness of how well or otherwise the covers protect soil against erosion caused by natural processes. While 72.8% of the region has been identified as needing soil conservation cover to protect the land against soil erosion, Figure 4.27 indicates that just 0.37% of that land has resulted in bare soil (ie, the soil conservation cover is very effective). Bare soil amongst natural vegetation is the highest contributor to erosion by natural processes, probably because it is present on Wellington's steepest and most unstable land, in the Tararua Range (Crippen & Hicks 2011). Farmland which needs – but consistently lacks – soil conservation cover contributed a significant portion (14%) of the total bare soil.

[12] The sum of the categories: natural vegetation, residual vegetation, forest plantations, farmland (natural SCC), farmland (residual SCC), farmland (planted SCC), farmland (SCC absent).

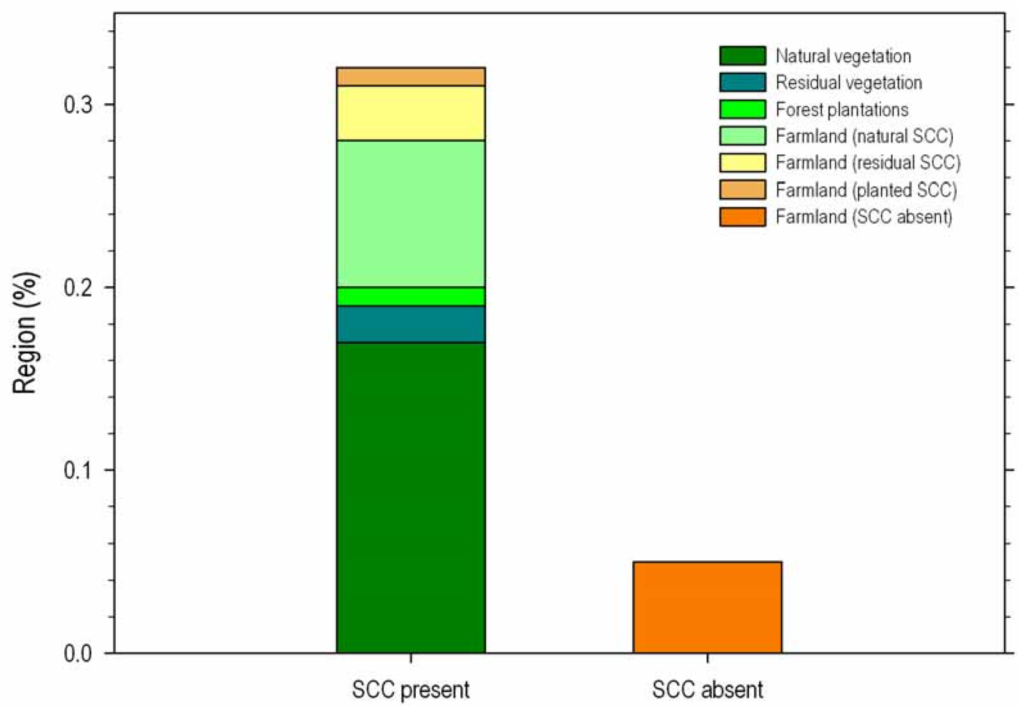


Figure 4.27: Extent of bare soil caused by natural processes according to soil conservation cover (SCC) in the Wellington region, based on a point survey analysis of aerial photographs taken in 2010 (adapted from Crippen & Hicks 2011)

4.3 Synthesis

Based on the results of the most recent round of soil quality monitoring, soils at most monitoring sites are in a reasonable condition. However, some land uses and certain land management practices are impacting on soil quality throughout the region. Vegetable growing sites recorded the worst soil quality results out of all of the land uses monitored, and at levels which could be affecting either production or the environment. Results indicate that soil at a large number of these sites is compacted and has a poor structure. Organic resources were low (in particular levels of total carbon), and this will also be affecting the physical quality of the soil. Due to low levels of total carbon, nitrogen levels were also low and soil biology was poor. Concentrations of Olsen P were very high throughout the vegetable growing sites; however, cadmium levels were not elevated, probably due to the use of phosphate fertilisers with low cadmium content.

The main soil quality issue for the dairy farm sites was compaction, with a majority of the sites having low macroporosity. Excessive levels of nutrients, both nitrogen and Olsen P, were also found in soil samples from some of the dairy farm sites; the highest concentrations of cadmium out of all the land uses were also found at the dairy farm sites.

Drystock farming soils had similar issues to dairy farm soils, but to a lesser degree. Compaction was common, but both nitrogen and Olsen P concentrations were a lot more variable; at some sites levels were excessive and at others they were deficient. This indicates a divergence in management of drystock sites and suggests that some drystock sites are becoming more intensively managed (with the same problems associated with dairy sites), and others are becoming less intensively managed (probably hill country and marginal pasture).

The soils at the cropping and horticultural sites were generally in good condition, although only seven cropping sites were sampled and all were considered to have compacted soils. Horticultural sites were affected by compaction to a small degree, and by either high or low concentrations of Olsen P. Soils on exotic forest sites were the least impacted of all the land uses monitored.

According to a 2010 aerial survey, the majority of the Wellington region's soil is intact, either on stable land surfaces that show no signs of past erosion, or on erosion-prone land surfaces that are inactive and well vegetated. However, 14% of the region's soil has been disturbed by land use activities on these stable land surfaces. The most prominent land use activity which has caused soil disturbance is farm and forest tracking, but other activities such as drains, earthworks, cultivation and livestock grazing have also disturbed soils to a lesser degree. A further 15% of the region's soil is located on unstable surfaces that have been disturbed by natural processes. Only a small percentage of disturbed surfaces have created bare soil across the region.

The steep landscape of the region means that soil conservation cover is needed across a majority of it. Of the farmland that requires some form of soil conservation cover, 58% currently has it, but a further 42% (approximately 89,300 ha) still requires some form of soil conservation cover for protection against erosion. Very small amounts of bare soil are created when soil conservation cover is present.

5. Temporal trends

This section examines trends in soil quality over time across selected land uses in the Wellington region that have been sampled on at least three occasions between 2000 and 2010. Changes in soil stability, soil disturbance, the amount of bare soil and the presence of soil conservation cover between 2002 and 2010 are also outlined.

5.1 Soil quality

Due to the nature of the soil quality monitoring programme, more intensive land uses are sampled more frequently. At present the dairy farm and vegetable growing sites are the only land use types to have been sampled on three separate occasions[13] – the minimum necessary to assess temporal trends:

- Dairy farm sites were first sampled between the years 2000 and 2004 when Greater Wellington's soil quality monitoring programme was first being established. These sites were then re-sampled over two years, 2006 and 2007, before being sampled for a third time in 2009.
- Vegetable growing sites were first sampled between the years 2000 and 2004, before being re-sampled over 2006 and 2007, and again in 2010.

5.1.1 Approach to analysis

Summary statistics were calculated for each soil quality indicator across the three sampling events and a One Way Repeated Measures ANOVA[14] statistical test was undertaken to evaluate whether changes in the mean values for each soil quality indicator across the three sampling rounds were statistically significant. A result was deemed statistically significant if the *p*-value of the test was less than 0.05.

5.1.2 Results

(a) Dairy farm sites

A summary of the dairy farm soil quality results from the three sampling events, 2000 to 2004, 2006 to 2007 and 2009, is presented in Table 5.1. The results are also presented by soil quality indicator in Figures 5.1 to 5.4.

Table 5.1 shows that, overall, there were significant changes in the mean values of most soil quality indicators between 2000 and 2009. The most significant changes were an increase in nutrients (both total nitrogen and Olsen P), macroporosity and cadmium. Statistically significant increases were also observed in mean total carbon and anaerobic mineralisable nitrogen concentrations, while a statistically significant decrease was observed in the mean C:N ratio. No statistically significant trends were evident in bulk density or soil pH values across the three sampling events.

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[13] Cropping sites have also been sampled on three occasions, however, only six sites fit into this land use type, so analysis was not performed on these sites. Note for the dairy and vegetable growing sites, only data from sites sampled across all three sampling events were included in the trend assessment (n=21 and n=14, respectively).

[14] This analysis assumes that sites are sampled at the same time. For the purposes of this report, it is assumed the first samples (which were sampled from 2000–04) were taken at an intermediate date of 2002.

Table 5.1: Summary of soil quality at dairy farm sites sampled across the Wellington region on three occasions between 2000 and 2009. Values in bold indicate a statistically significant difference in the mean value of a soil quality indicator between sampling years (95% confidence interval). TR=target range

Indicator		2000–04 *(Sample 1)* *n=21*	2006–07 *(Sample 2)* *n=21*	2009 *Sample 3)* *n=21*	*p*-value
Bulk density (Mg/m³)	Mean	1.07	1.10	1.06	0.189
	Median	1.11	1.12	1.05	
	Std dev.	0.20	0.15	0.18	
	Range	0.62 – 1.41	0.78 – 1.33	0.75 – 1.48	
	n outside TR	2	–	1	
Macroporosity (@-10kPa, %)	Mean	6.97	10.00	9.53	**<0.001**
	Median	6.60	8.83	8.73	
	Std dev.	5.87	4.26	3.95	
	Range	1.10 – 27.27	4.20 – 21.23	2.80 – 17.67	
	n outside TR	16	12	13	
Total carbon (% w/w)	Mean	6.16	6.23	6.58	**0.010**
	Median	5.12	6.29	6.03	
	Std dev.	2.62	2.28	1.98	
	Range	2.87 – 12.11	3.24 – 12.48	4.15 – 11.46	
	n outside TR	–	–	–	
Total nitrogen (% w/w)	Mean	0.55	0.58	0.62	**0.002**
	Median	0.46	0.53	0.54	
	Std dev.	0.22	0.20	0.17	
	Range	0.25 – 1.00	0.29 – 1.05	0.38 – 0.95	
	n outside TR	8	5	6	
C:N[1] (ratio)	Mean	11.18	10.82	10.63	**0.006**
	Median	11.13	10.73	10.67	
	SD	1.06	0.85	0.71	
	Range	9.67 – 14.55	9.36 – 12.14	9.49 – 12.11	
	TR	n/a	n/a	n/a	
AMN (mg/kg)	Mean	157	176	192	**0.006**
	Median	148	160	192	
	Std dev.	66.36	69.28	53.38	
	Range	64 – 329	86 – 326	126 – 288	
	n outside TR	1	3	3	
Soil pH	Mean	5.89	5.94	6.05	0.170
	Median	5.96	5.84	5.98	
	Std dev.	0.27	0.34	0.33	
	Range	5.22 – 6.28	5.38 – 6.95	5.45 – 6.55	
	n outside TR	–	1	–	
Olsen P (mg/kg)	Mean	49	52	69	**<0.001**
	Median	38	45	68	
	Std dev.	24.54	23.63	24.22	
	Range	20 – 105	21 – 104	23 – 114	
	n outside TR	1	1	2	
Cadmium (mg/kg)	Mean	0.41	0.48	0.50	**<0.001**
	Median	0.35	0.40	0.50	
	Std dev.	0.18	0.21	0.14	
	Range	0.10 – 0.90	0.20 – 1.10	0.33 – 0.89	
	n outside TR[2]	2	4	4	

[1] Carbon:nitrogen ratio does not have a target range, but is useful to assist with interpreting soil quality results.

[2] Number of sites higher than the ‘A’ trigger value of the TFMS (Ministry of Agriculture and Forestry 2011).

Figure 5.1 illustrates the increase in Olsen P concentrations in dairy farm soils over time, from a mean of 49 mg/kg in 2000–04 to a mean of 69 mg/kg in 2009. While only one or two of the dairy farm sites sampled had Olsen P concentrations above the upper threshold values of the target range in any sampling event, as noted in Section 4.1.2(d), based on current knowledge the current upper threshold limit for Olsen P of 100 mg/kg is considered too high, and could be reduced to 40 mg/kg for pasture, horticulture and cropping on sedimentary soils (Taylor 2011b). If the upper threshold value was reduced to 40 mg/kg, nearly all of the dairy farm sites sampled in 2009 would have Olsen P concentrations above this value.

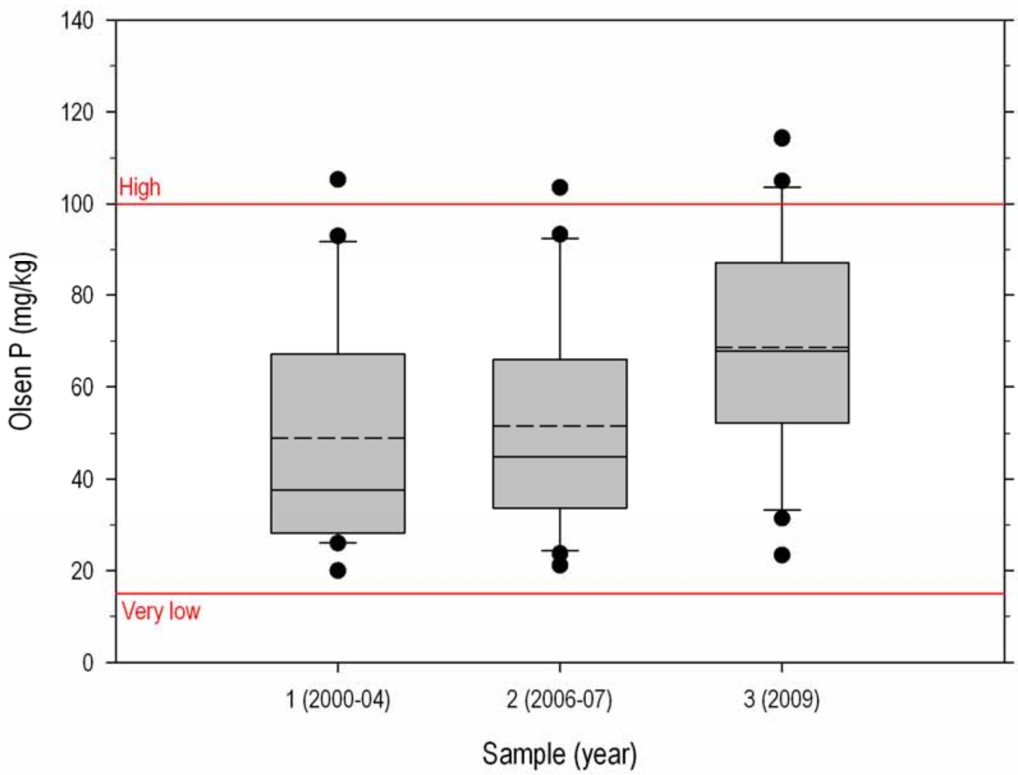

Figure 5.1: Box plot summarising Olsen P concentrations in soils from dairy farm sites sampled on three occasions between 2000 and 2009. The area between the red lines represents the target range for dairy soils.

Mean levels of total nitrogen also increased significantly (p=0.002) over the three sampling events, from 0.55% w/w in 2000–04, to 0.58% w/w in 2006–07, to 0.62% w/w in 2009 (Figure 5.2). In addition, there were a number of sites across each sampling event that recorded total nitrogen concentrations above the upper threshold value of the target range (indicating nitrogen levels are high). In 2000–04, soil samples from eight sites recorded high nitrogen concentrations, while samples from five and six sites recorded high nitrogen concentrations in 2006–07 and 2009, respectively.

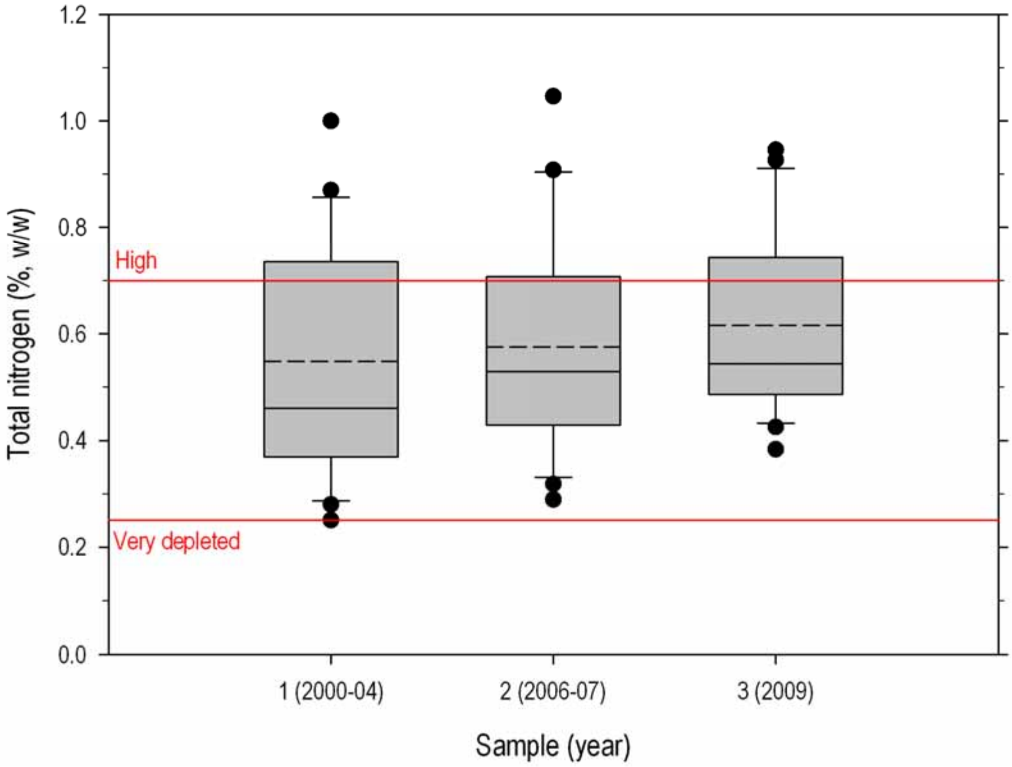

Figure 5.2: Box plot summarising total nitrogen content in soils from dairy farm sites sampled on three occasions between 2000 and 2009. The area between the red lines represents the target range.

Mean cadmium concentrations increased from 0.41 mg/kg in 2000–04 to 0.48–0.50 mg/kg in subsequent soil sampling (Figure 5.3). While the number of individual dairy farm sites with soil concentrations above the 'A' trigger level of the Ministry of Agriculture and Forestry (2011) Tiered Fertiliser Management System (TFMS) was not high across the sampling events, a concern is that both the mean and median cadmium concentrations are getting closer to the 'A' trigger level.

While mean macroporosity values also increased significantly ($p<0.001$) over the three soil sampling events (Figure 5.4), in contrast with the nutrient and cadmium results, this increase represents a positive trend. By 2009, there were also fewer dairy farm sites not meeting the minimum target value; 12 compared with 16 sites in 2000–04. However, despite this being an improving trend, overall, macroporosity values are still consistently low and soil samples from a large proportion of sites have recorded values below the lower threshold value of the target range in every year of sampling, indicating compaction (Figure 5.4).

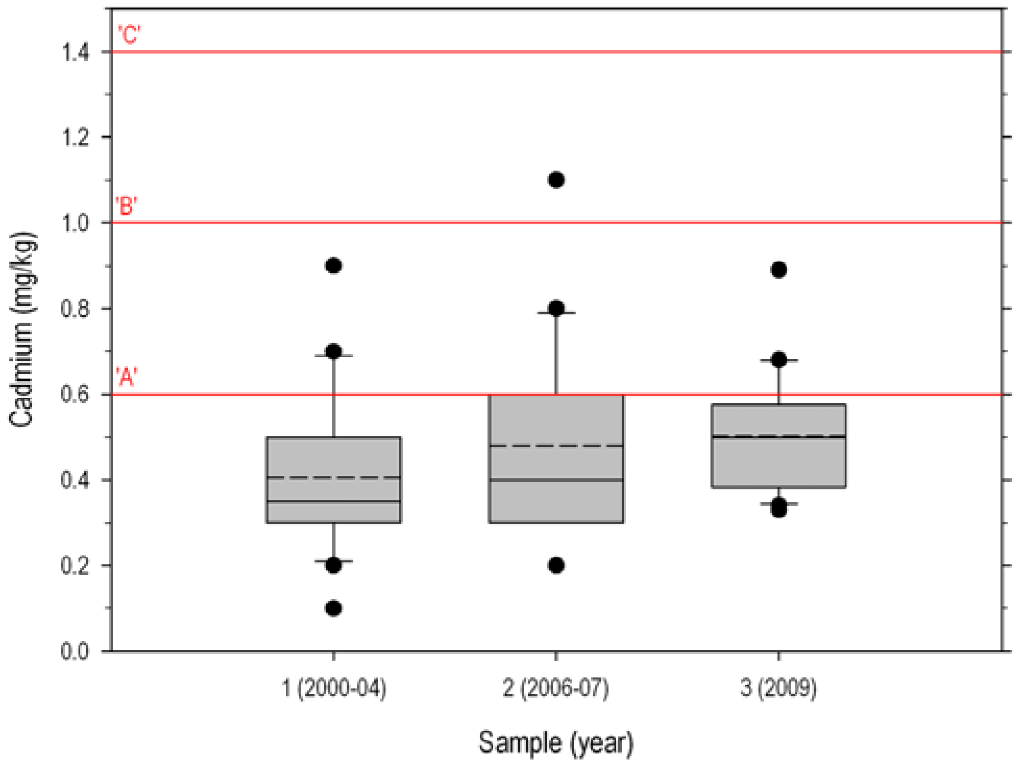

Figure 5.3: Box plot summarising total recoverable cadmium concentrations in soils from dairy farm sites sampled on three occasions between 2000 and 2009

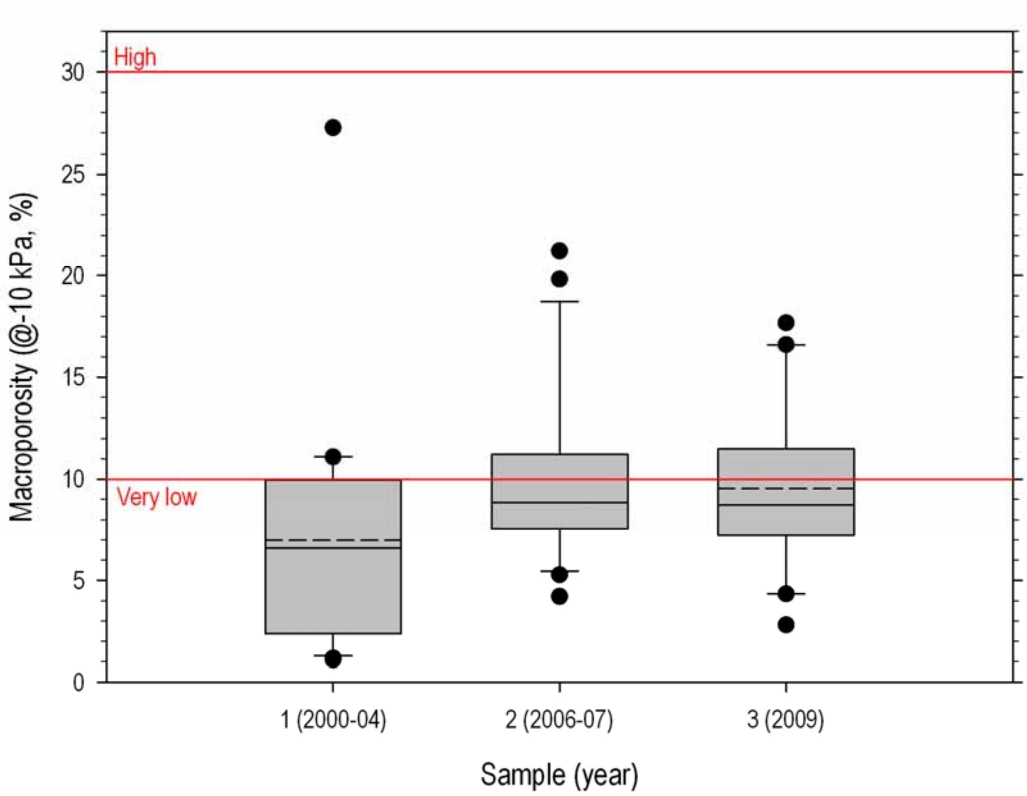

Figure 5.4: Box plot summarising soil macroporosity values for dairy farm soils sampled on three occasions between 2000 and 2009. The area between the red lines represents the target range.

Statistically significant increases in mean total carbon (*p*=0.01) and anaerobic mineralisable nitrogen (AMN) (*p*=0.006) concentrations were also found over the course of the three sampling events, concentrations of the latter increasing from a mean of 157 mg/kg in 2000–04 to a mean of 192 mg/kg in 2009 (Table 5.1). Generally AMN concentrations remained within the target range over all the years of sampling, with the exception of soil samples from the odd site returning concentrations that were too high. Given that AMN is used as a surrogate for microbial biomass, the results indicate that soil biology (microbial activity) is particularly healthy at the dairy farm sites.

Even though total nitrogen and total carbon concentrations increased over the three sampling events, the ratio of carbon to nitrogen (C:N) significantly decreased over the same period (*p*=0.006). Although there currently is no target range for C:N, it is a good indicator of change and shows that levels of nitrogen are increasing at a greater rate than carbon.

(b) Vegetable growing sites

A summary of the vegetable growing soil quality results from the three sampling events, 2000 to 2004, 2006 to 2007, and 2010 is presented in Table 5.2. The results are also presented by soil quality indicator in Figures 5.5 to 5.10.

Table 5.2 shows that, overall, there were very few statistically significant changes in the mean values of key soil quality indicators between 2000 and 2010. Mean values of the C:N ratio decreased over the three sampling events (*p*<0.001), while mean anaerobic mineralisable nitrogen (AMN) concentrations increased (*p*=0.047).

Although the C:N ratio is not one of the core soil quality indicators and has no target range, it is considered a good indicator of change in soil quality. When soil samples were first taken in 2000–04 the mean C:N was 12.35; this reduced to 11.01 in 2006–07 and was 11.10 in 2010 (Figure 5.5). This indicates that nitrogen is accumulating in vegetable growing soils at a greater rate than carbon.

Despite an overall increase in mean concentrations between 2000 and 2010, AMN concentrations have been consistently low (Figure 5.6). Soil samples from two sites in 2000–04 and three sites in 2010 recorded AMN concentrations below the lower threshold of the target range. While this indicates that soil biology is not particularly healthy at the vegetable growing sites, the overall increase in mean AMN concentrations suggests soil biology may be improving.

Table 5.2: Summary of soil quality at vegetable growing sites sampled across the Wellington region on three occasions between 2000 and 2010. Values in bold indicate a statistically significant difference in the mean value of a soil quality indicator between sampling years (95% confidence interval). TR=target range

Indicator		2000–04 *(Sample 1)* *n=14*	2006–07 *(Sample 2)* *n=14*	2010 *Sample 3)* *n=14*	*p*-value
Bulk density (Mg/m^3)	Mean	1.28	1.28	1.34	0.173
	Median	1.34	1.26	1.35	
	Std dev.	0.16	0.16	0.17	
	Range	0.96 – 1.47	1.03 – 1.70	1.06 – 1.65	
	n outside TR	4	2	4	
Macroporosity (@-10kPa, %)	Mean	15.60	17.70	11.80	0.068
	Median	14.25	18.42	11.57	
	Std dev.	5.94	7.09	7.85	
	Range	6.60 – 29.13	1.10 – 28.23	1.93 – 21.23	
	n outside TR	1	2	6	
Total carbon (% w/w)	Mean	2.60	2.44	2.43	0.517
	Median	2.12	1.86	1.91	
	Std dev.	1.32	1.29	1.15	
	Range	1.32 – 5.56	1.26 – 5.16	1.23 – 4.66	
	n outside TR	8	9	9	
Total nitrogen (% w/w)	Mean	0.21	0.22	0.21	0.598
	Median	0.18	0.18	0.17	
	Std dev.	0.09	0.09	0.09	
	Range	0.10 – 0.38	0.13 – 0.39	0.12 – 0.39	
	n outside TR	–	–	–	
C:N[1] (ratio)	Mean	12.35	11.01	11.10	<0.001
	Median	12.33	10.62	10.83	
	Std dev.	1.56	1.35	1.05	
	Range	10.19 – 15.77	9.11 – 14.80	9.99 – 14.29	
	n outside TR	n/a	n/a	n/a	
AMN (mg/kg)	Mean	39	58	48	0.047
	Median	36	55	40	
	Std dev.	19.85	25.34	36.11	
	Range	2 – 70	16 – 107	13 – 146	
	n outside TR	2	-	3	
Soil pH	Mean	6.38	6.28	6.15	0.362
	Median	6.34	6.10	6.13	
	Std dev.	0.74	0.57	0.60	
	Range	5.12 – 7.37	5.68 – 7.37	5.18 – 7.27	
	n outside TR	–	–	–	
Olsen P (mg/kg)	Mean	113	94	117	0.514
	Median	108	90	128	
	Std dev.	74.32	58.28	73.10	
	Range	22 – 256	22 – 186	14 – 241	
	n outside TR	7	7	9	
Aggregate stability (m.w.d.)	Mean	0.79	0.88[2]	0.53[3]	0.118
	Median	0.68	0.61[2]	0.43[3]	
	Std dev.	0.54	0.72[2]	0.34[2]	
	Range	0.29 – 1.80	0.28 – 2.41[2]	0.27 – 1.19[3]	
	n outside TR	n/a	n/a	n/a	

[1] Carbon:nitrogen ratio does not have a target range, but is useful to assist with interpreting soil quality results.

[2] Analysis was limited to only 13 sites.

[3] Analysis was limited to only 6 sites.

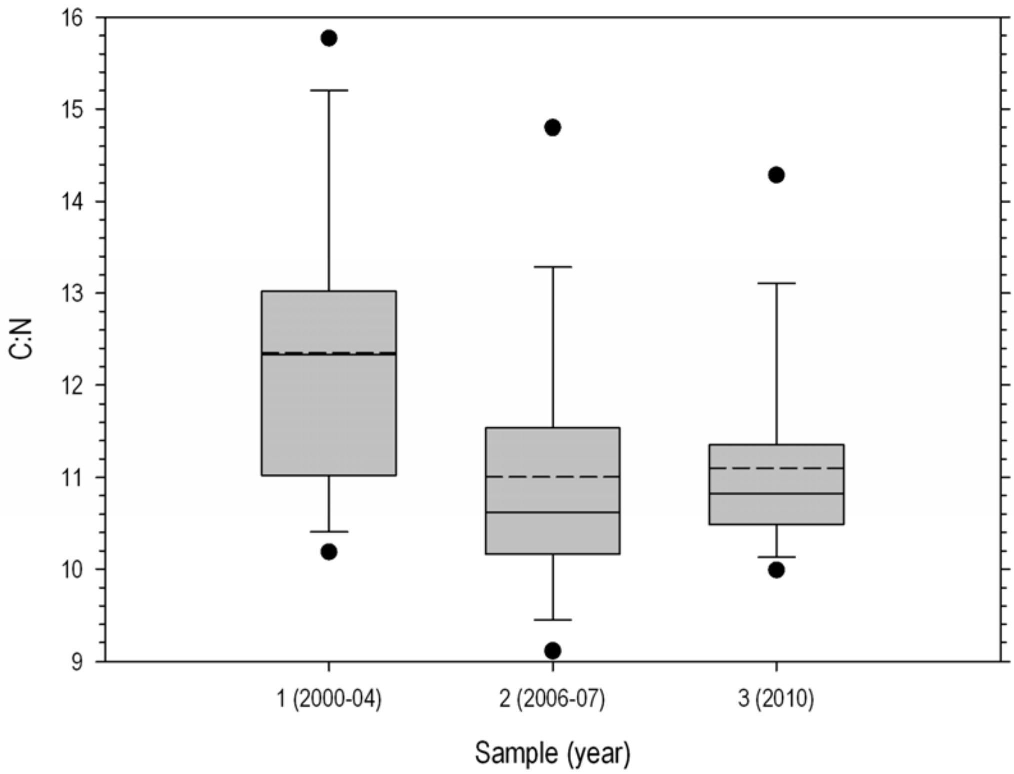

Figure 5.5: Box plot summarising carbon to nitrogen ratios (C:N) of soils from vegetable growing sites sampled on three occasions between 2000 and 2010

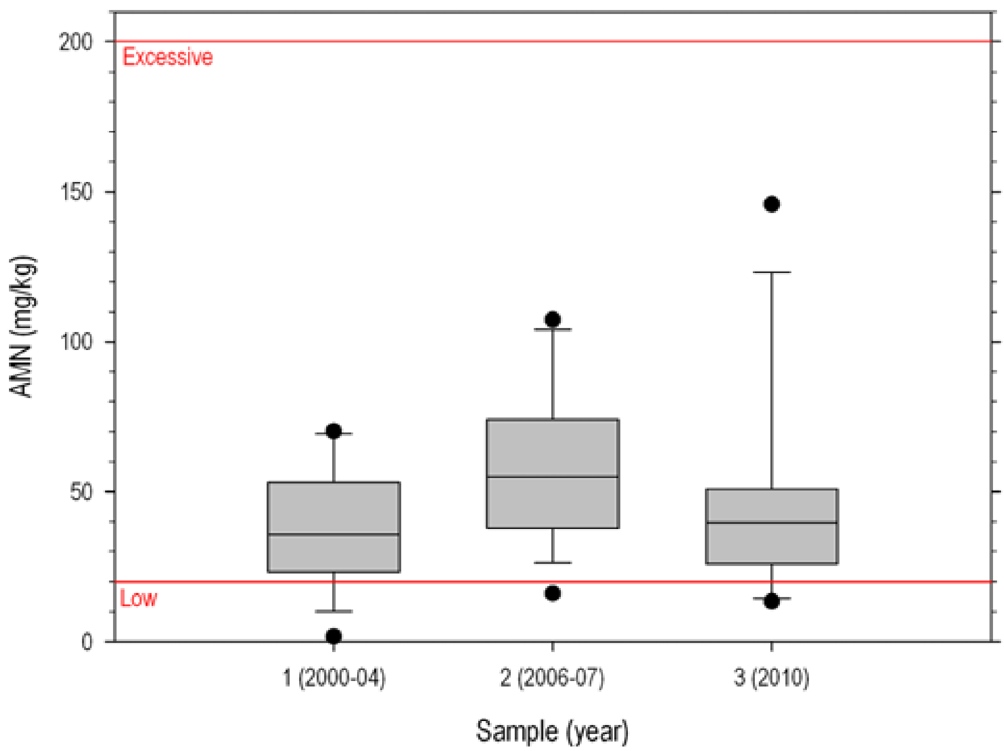

Figure 5.6: Box plot summarising anaerobic mineralisable nitrogen (AMN) concentrations in soils from vegetable growing sites sampled on three occasions between 2000 and 2010. The area between the red lines represents the target range.

Although no statistically significant changes were observed in the mean values of other soil quality indicators between 2000 and 2010, many of the other indicators returned poor results across all three sampling events. For example:

- Total carbon levels were low when soil samples were first taken over 2000–04, with eight sites recording levels below the lower threshold value of the target range – Figure 5.7 indicates there has not been any improvement since then and shows that total carbon at the only site with any significant amount of carbon in its soils (shown as the black dot outlier on the box plot) decreased from 5.56% in 2000–04 to 4.66% in 2010.

- Olsen P levels have remained consistently high in vegetable growing soils (Figure 5.8). In 2010, the median Olsen P concentration was 128 mg/kg (the highest median across the three surveys). In addition, nine of the 14 sites had soil Olsen P levels above the upper threshold value of the target range in 2010, two more than in both 2000–04 and 2006–07. As previously noted for the dairy farm soils, the current upper threshold limit for Olsen P of 100 mg/kg is considered too high and if this limit was reduced to 40 mg/kg as recommended by Taylor (2011b), nearly all of the vegetable growing sites sampled in 2010 would have recorded Olsen P concentrations above this value.

- Total nitrogen values were very low across all three sampling periods. There is no target range for nitrogen at vegetable growing sites because optimal nitrogen levels will depend on the crop type grown and available nitrogen is typically provided by fertiliser addition. However, to provide some context, the median values of 0.18% in 2000–04 and 2006-07, and 0.17% in 2010 (Table 5.2), would be considered very depleted for soils under a pastoral use.

- Bulk density, macroporosity and aggregate stability values at some sites indicate that the physical quality of the soils is showing signs of deterioration. Between two and four sites recorded bulk density results indicative of soil compaction in each sampling event (Figure 5.9), and the number of sites with macroporosity values below the target range lower threshold value of 10% increased from one in 2000–04 to six of 14 sites in 2010 (Figure 5.10). This indicates that many vegetable growing soils are compacted. While the number of sites analysed for aggregate stability over the years has varied, the results across all sites have been poor; even though just six sites were assessed for aggregate stability in 2010, levels continued to be well below the lower threshold of the target range (Figure 5.11), indicating poor soil structure – this in turn means the soil is more susceptible to erosion (particularly if bare), and losses in soil carbon.

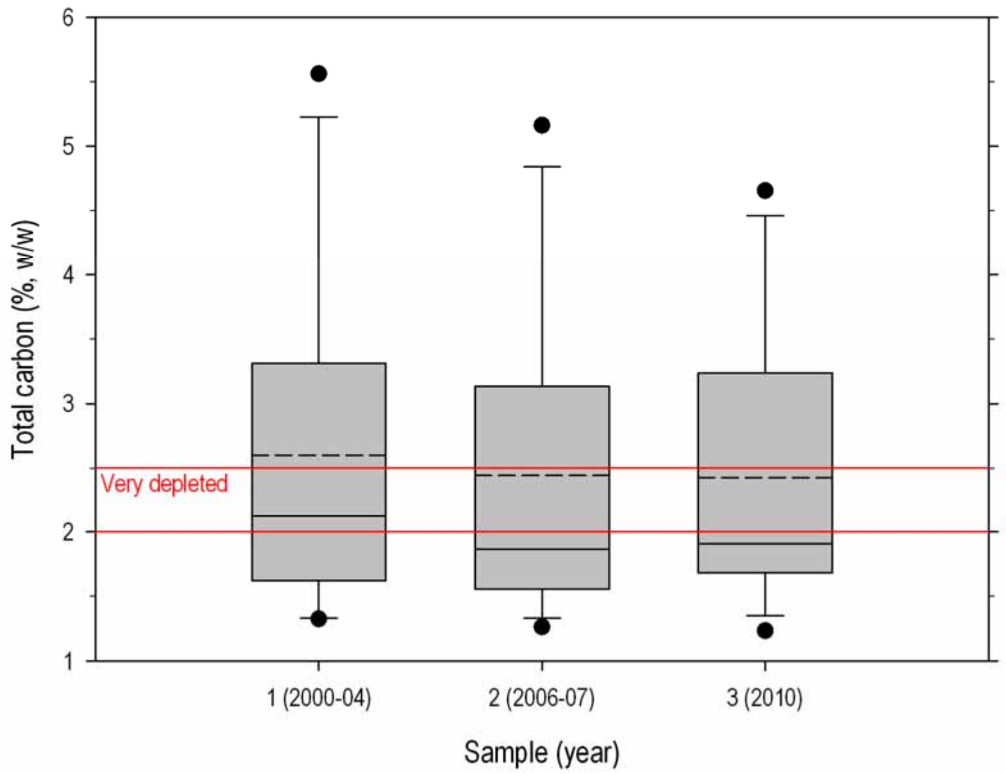

Figure 5.7: Box plot summarising total carbon content in soils from vegetable growing sites sampled on three occasions between 2000 and 2010. The red lines represent the lower limit of the target range*.

* Recent soils have a slightly higher low threshold value than all other Soil Orders except Organic

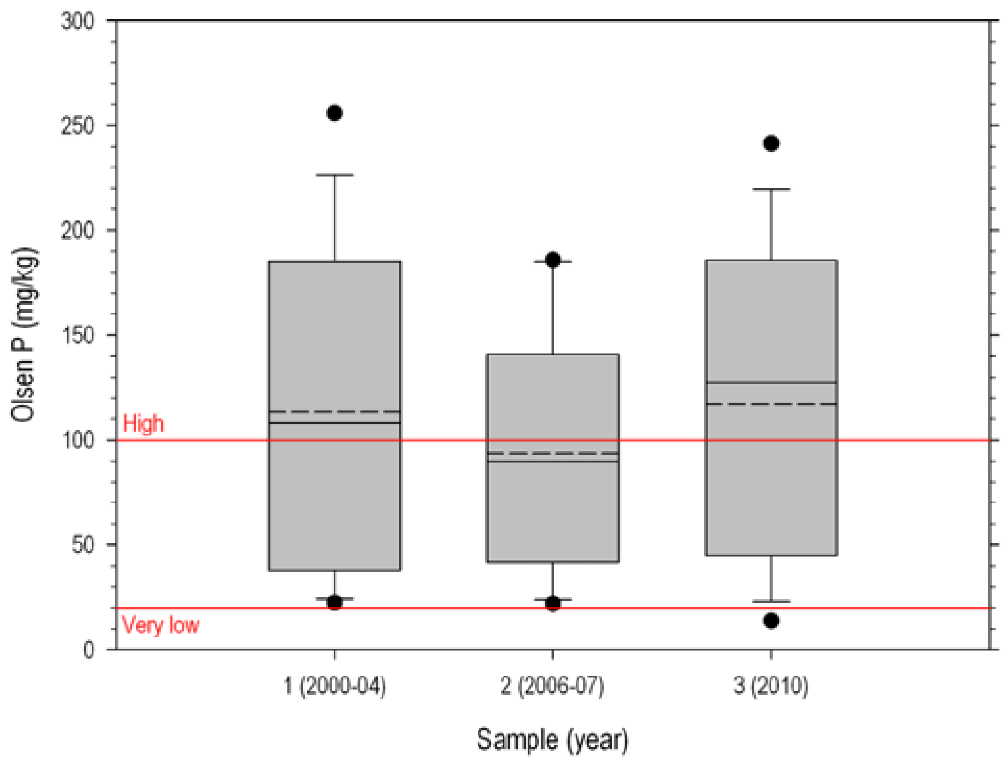

Figure 5.8: Box plot summarising Olsen P concentrations in soils from vegetable growing sites sampled on three occasions between 2000 and 2010. The area between the red lines represents the target range.

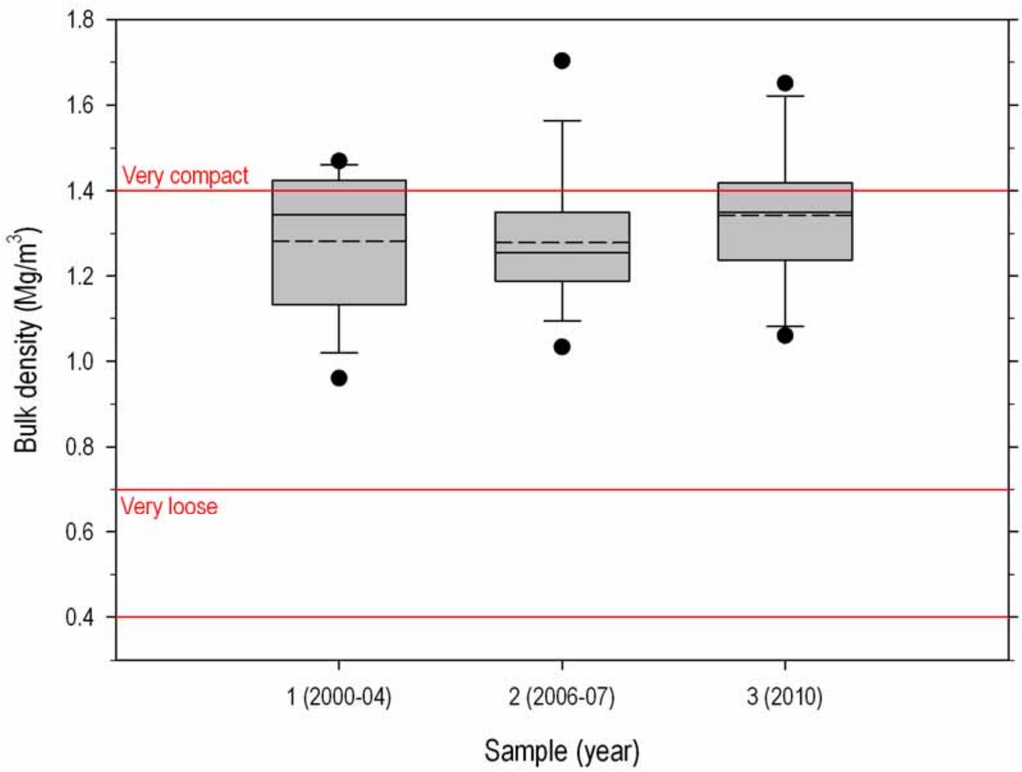

Figure 5.9: Box plot summarising bulk density values of soils from vegetable growing sites sampled on three occasions between 2000 and 2010. The area between the red lines represents the target range.

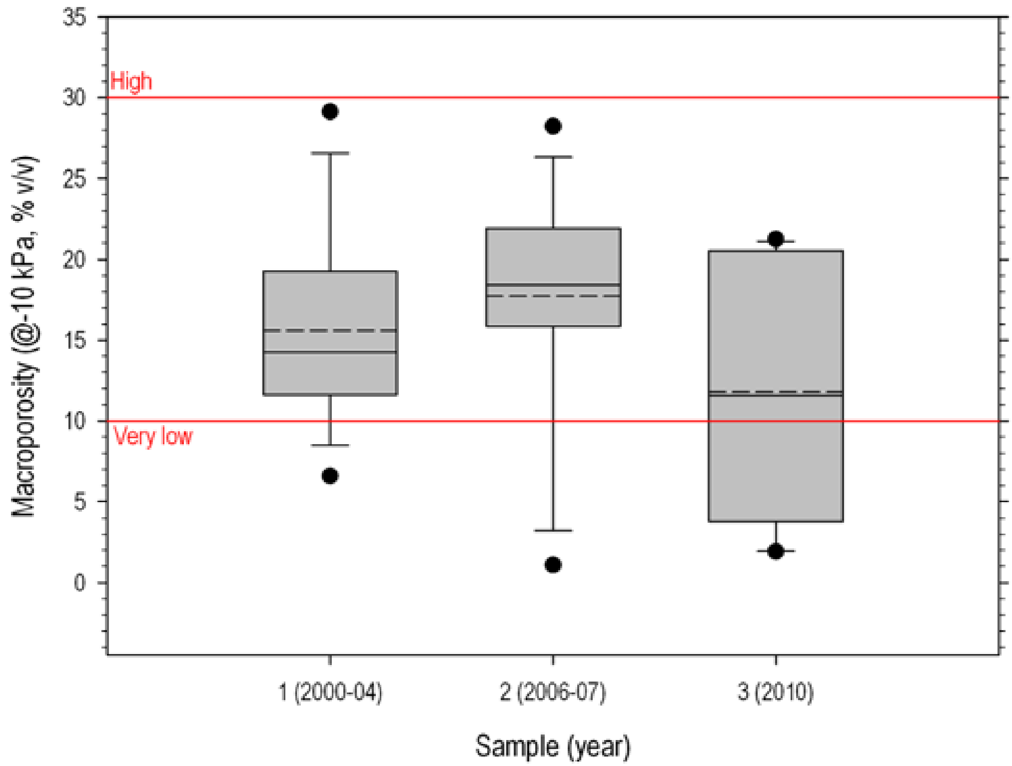

Figure 5.10: Box plot summarising soil macroporosity values at vegetable growing sites sampled on three occasions between 2000 and 2010. The area between the red lines represents the target range.

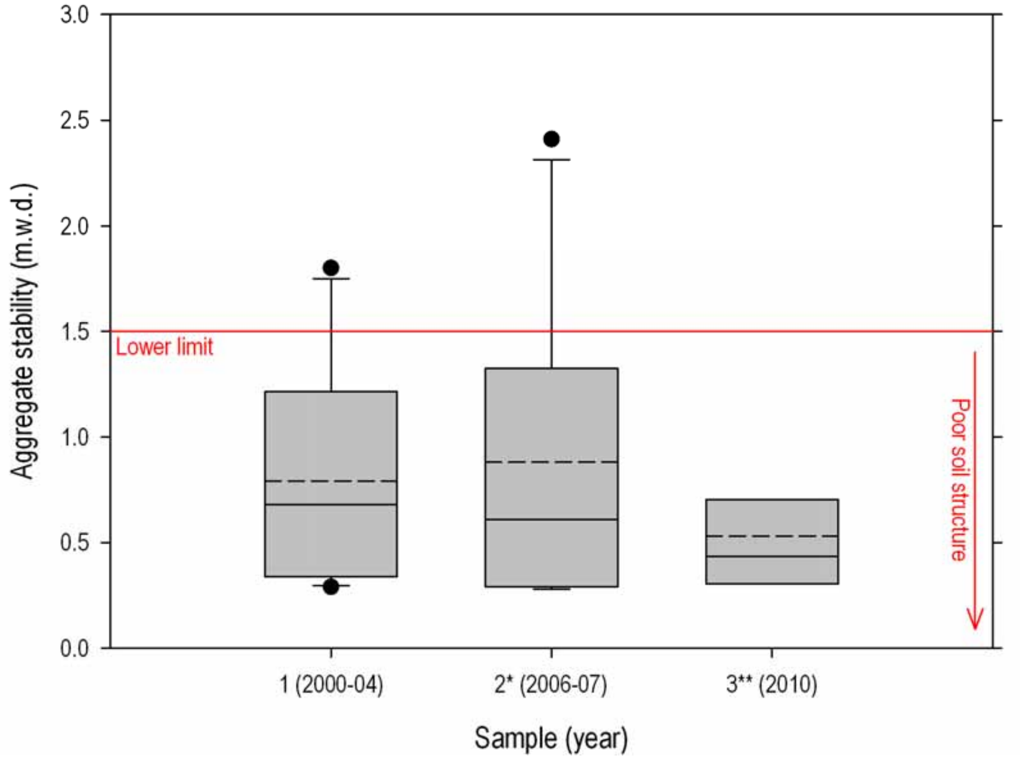

Figure 5.11: Box plot summarising aggregate stability values for soils from vegetable growing sites sampled on three occasions between 2000 and 2010. The area between the red lines represents the target range.

* In 2006–07 analysis was limited to 13 sites

** In 2010 analysis was limited to 6 sites

5.2 Soil stability and conservation cover

5.2.1 Approach to analysis

Soil stability surveys involve the interpretation of aerial photographs, so they are only able to be undertaken when aerial photography is available for the region. As outlined in Section 2.2, a soil stability survey was undertaken by Crippen and Hicks (2004), using aerial photographs taken of the Wellington region in 2002[15]. A second soil stability survey was undertaken by Crippen and Hicks (2011), using aerial photographs taken of the region in 2010. As the soil stability surveys analyse the same site locations, comparisons can be made between the two surveys and changes can be identified. A minimum of a third survey would need to be undertaken before any trends could be observed.

The following sections outline the differences in soil stability, disturbance and bare soil, as well as differences in the presence and effectiveness of soil conservation covers, between 2002 and 2010.

5.2.2 Soil stability

The amount of soil in the Wellington region located on stable or erosion-prone land surfaces which are inactive increased from 76% of the region in 2002, to 79% of the region in 2010 (Figure 5.12). This is largely due to the increase in

[15] As noted in Section 2.2.3, the aerial photographs for the survey were taken over a period between 2001 and 2003, but for the purposes of this report, the survey is considered an interpretation of soil stability at 2002.

erosion-prone land surfaces which are inactive (from 31% to 35% in 2002 and 2010, respectively).

In contrast, actively unstable land surfaces that were recently or still eroding due to natural processes decreased from 18% of the region in 2002 to 15% of the region in 2010. Of this, 9% was eroding and freshly disturbed in 2002, which decreased to 6% in 2010. This suggests that some formerly eroded or eroding land surfaces have re-vegetated over this time period and become inactive.

The amount of soil that was extensively modified through either being covered by urban buildings and parks, rural buildings, infrastructure and roads – or was submerged beneath water – remained as 6% of the region in both 2002 and 2010.

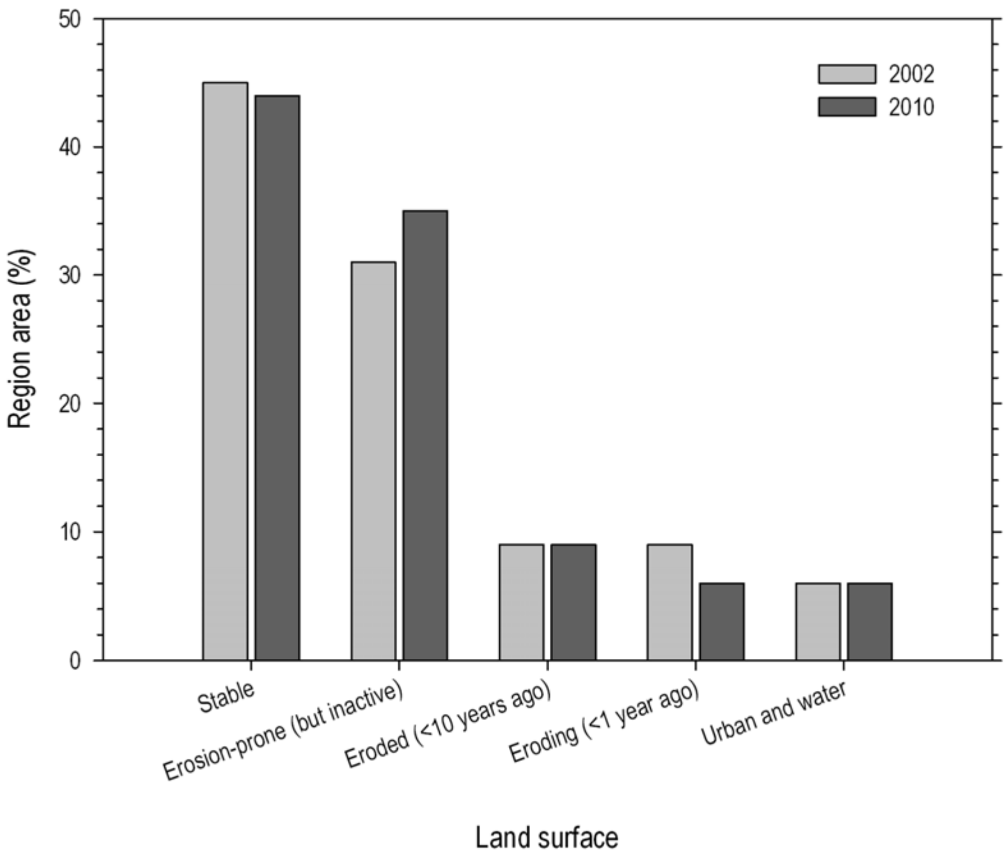

Figure 5.12: Soil stability in the Wellington region as determined from point survey analyses of aerial photographs taken in 2002 and 2010 (adapted from Crippen & Hicks 2011)

5.2.3 Soil disturbance and bare soil

Changes in soil stability can also reflect changes in soil disturbance and the amount of bare soil created by disturbed soil. In total, soil disturbance (caused by both land use activities and natural processes) was found across 29% of the region in both 2002 and 2010. However, changes in the cause of disturbance (either land use activities or natural processes) are apparent between 2002 and 2010 (Figure 5.13).

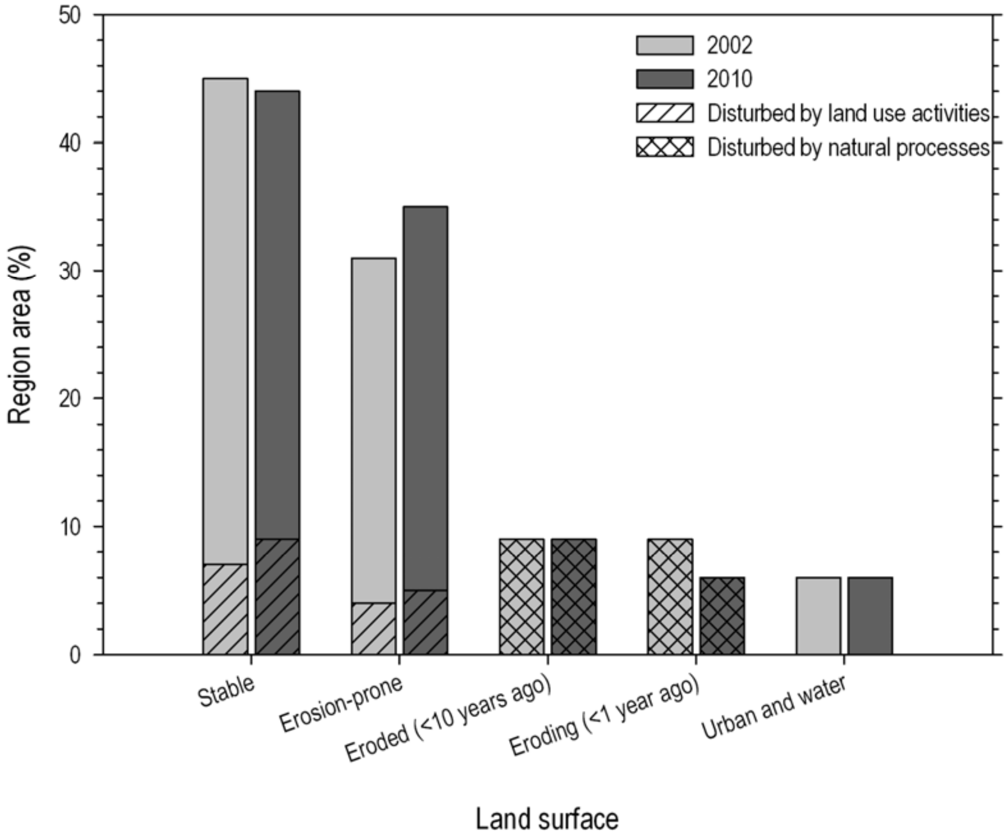

Figure 5.13: Soil disturbance caused by both land use activities and natural processes in the Wellington region as determined from point survey analyses of aerial photographs taken in 2002 and 2010 (adapted from Crippen & Hicks 2011)

In 2002, 11% of the Wellington region's soil was disturbed by land use activities, which increased to 14% of the region in 2010 (equivalent to over 24,000 hectares). The increase in soil disturbance caused by land use activities occurred on both stable surfaces (increase of 2%), and erosion-prone surfaces (increase of 1%). In contrast, the amount of soil in the region disturbed by natural processes decreased from 18% of the region in 2002 to 15% of the region in 2010 (equivalent to over 24,000 hectares). All of the decrease occurred on freshly eroding land surfaces.

The amount of soil disturbance and bare soil caused by specific land use activities and natural processes are presented in Figures 5.14a and 5.14b, respectively. Overall, soil disturbance caused by land use activities increased from 2002 to 2010, although the changes vary between the specific activities (Figure 5.14a). The amount of soil disturbed by farm and forest tracking increased by 2.1% of the region's area, equivalent to approximately 17,000 hectares, from 2002 to 2010. Other land use activities which disturbed more soil in 2002 than 2010 include cultivation for crops and spraying for pasture renewal. The amount of soil disturbed from grazing pressure decreased by 1.0% of the region's area (approximately 8,000 ha) and soil disturbance caused by drains and earthworks also decreased.

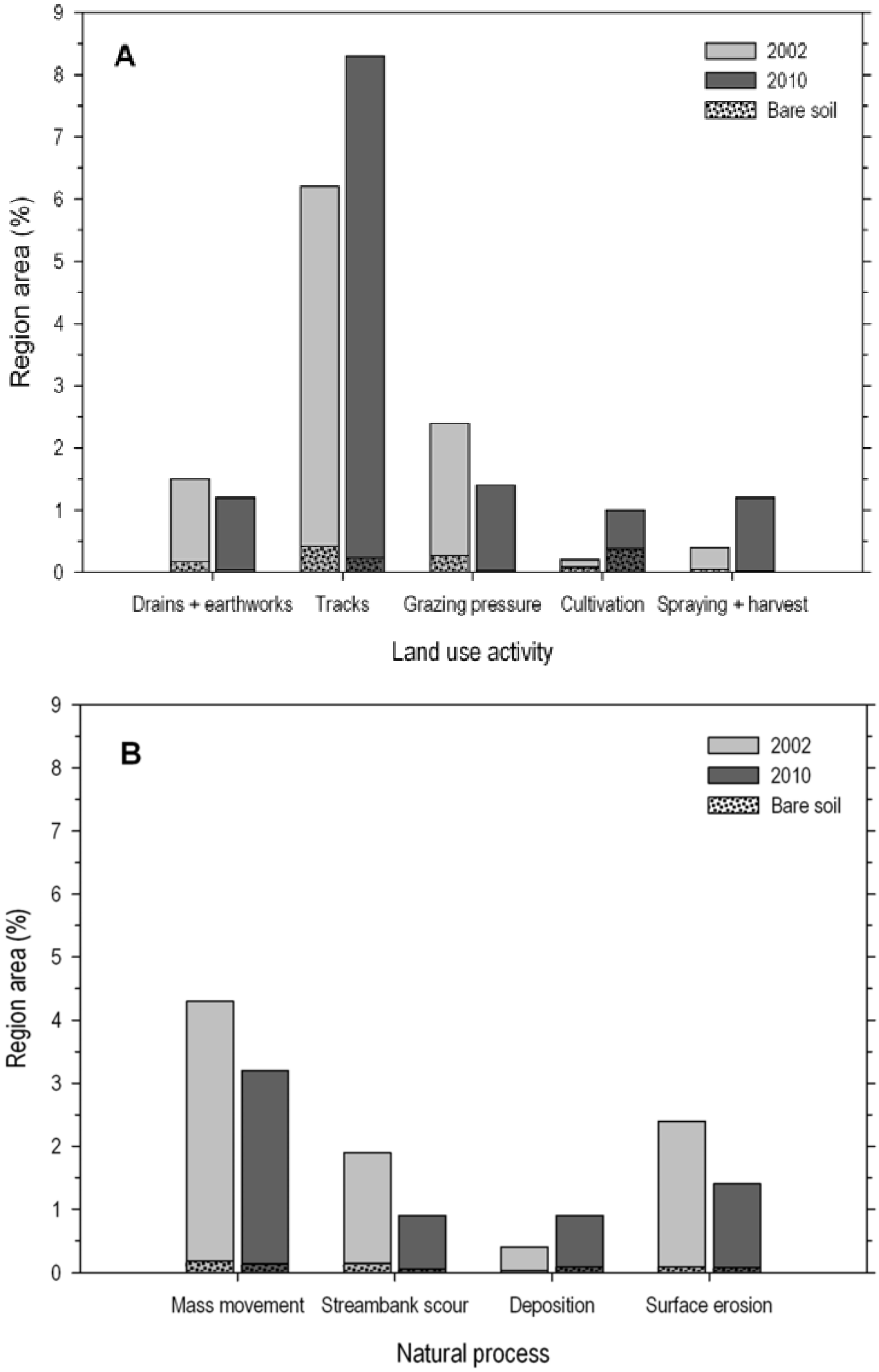

Figure 5.14: Soil disturbance and associated bare soil caused by (a) land use activities and (b) natural processes in the Wellington region as determined from point survey analyses of aerial photographs taken in 2002 and 2010 (adapted from Crippen & Hicks 2011)

A small proportion of soil disturbed by land use activities is made up of bare soil (Figure 5.14a). In 2002, 1.0% of the region (approximately 8,000 ha) was bare soil caused by land use disturbance, which decreased to 0.7% of the region (approximately 5,600 ha) in 2010. Farm and forest tracking created the most bare soil in 2002, approximately 4,200 ha, while grazing pressure also caused approximately 2,200 ha of bare soil. Both of these activities decreased the amount of bare soil created in 2010 to approximately 1,800 ha and 240 ha, respectively. The largest increase in bare soil was from cultivation, which increased from approximately 650 ha in 2002 to over 3,000 ha in 2010.

In total, soil disturbance caused by natural processes decreased from 2002 to 2010, however the changes differ between the specific processes (Figure 5.14b). Mass movement (land slides, slumps, earth flows and debris avalanches), stream bank scour and surface erosion (sand blow, sheet wash and rock falls) all decreased by about 1.0% of the region's area, or approximately 8,000 ha. The only natural process to increase the amount of soil disturbed from 2002 to 2010 was stream bank deposition.

The amount of bare soil caused by natural processes is generally less than that caused by land use activities (Figure 5.14b). The amount of bare soil in the region caused by natural processes remained consistent at 0.4% of the region's area or approximately 4,000 ha. The main causes in 2002 and 2010 were mass movement (landslides, earth flows, slumps and debris avalanches) and fluvial activity (gullies, stream bank scour and deposition).

Both land use activities and natural processes vary between land uses, due to the different land use practices and landscapes which dominate each land use type. Drystock farming was the largest contributor of bare soil out of the different land use types in both 2002 and 2010 (Figure 5.15). However, the amount of

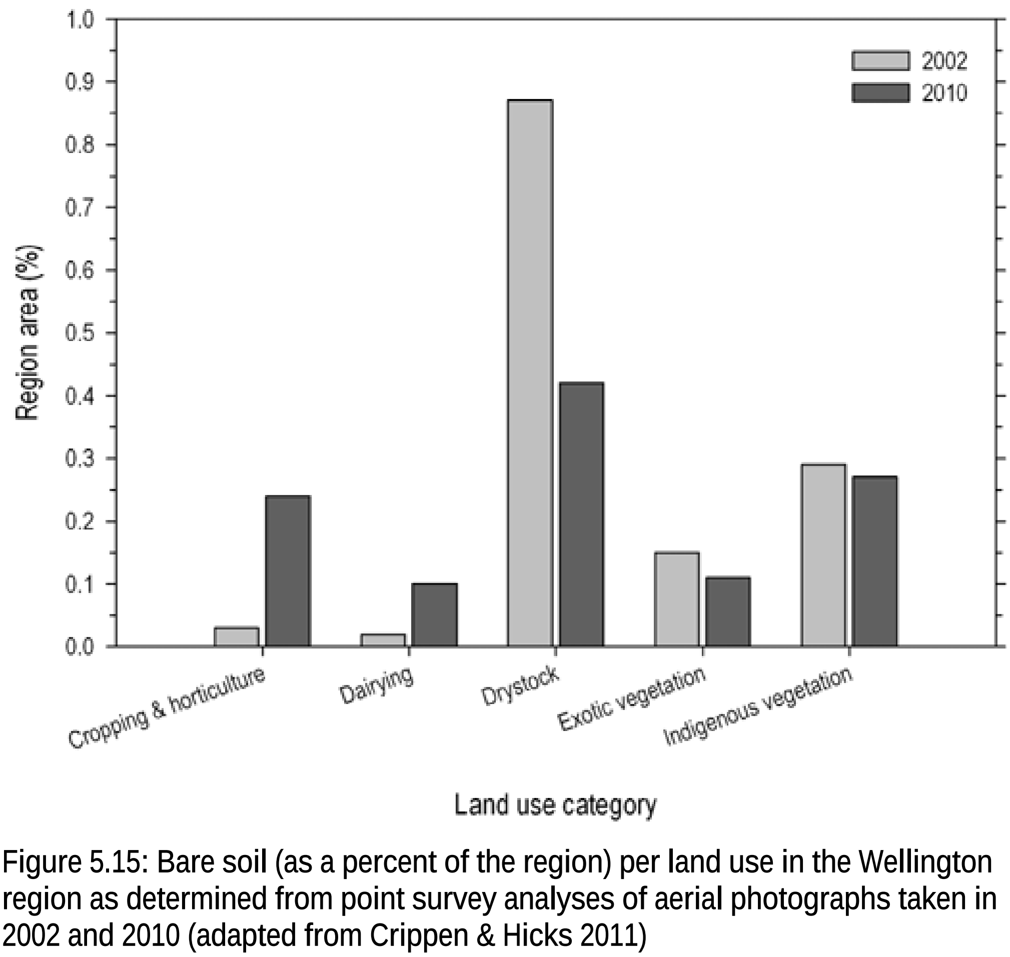

Figure 5.15: Bare soil (as a percent of the region) per land use in the Wellington region as determined from point survey analyses of aerial photographs taken in 2002 and 2010 (adapted from Crippen & Hicks 2011)

bare soil from drystock farming decreased from 0.87% of the region (approximately 7,000 ha) in 2002 to 0.42% of the region (approximately 3,400 ha) in 2010. The amount of bare soil caused by cropping and horticulture increased across the region by approximately 1,700 ha, from approximately 250 ha in 2002 to 1,950 ha in 2010. There was a smaller increase in the amount of bare soil caused by dairy farming, increasing from approximately 160 ha in 2002 to approximately 820 ha in 2010. Bare soil created by exotic vegetation and indigenous vegetation decreased slightly between 2002 and 2010.

5.2.4 Soil conservation covers

In 2002, 59.9% of the region had some form of vegetative soil conservation cover, and this increased to 61.7% of the region in 2010, indicating that a further 1.8% of the region (approximately 14,600 ha) has soil conservation cover in 2010 compared to 2002 (Figure 5.16). Natural vegetation (mainly trees and scrub) provided the majority (34.6%) of soil conservation cover for the region in both 2002 and 2010, and such cover has remained reasonably consistent. The increase in soil conservation cover is mainly from forest plantations, which increased by approximately 13,800 ha (1.7% of the region) between 2002 and 2010.

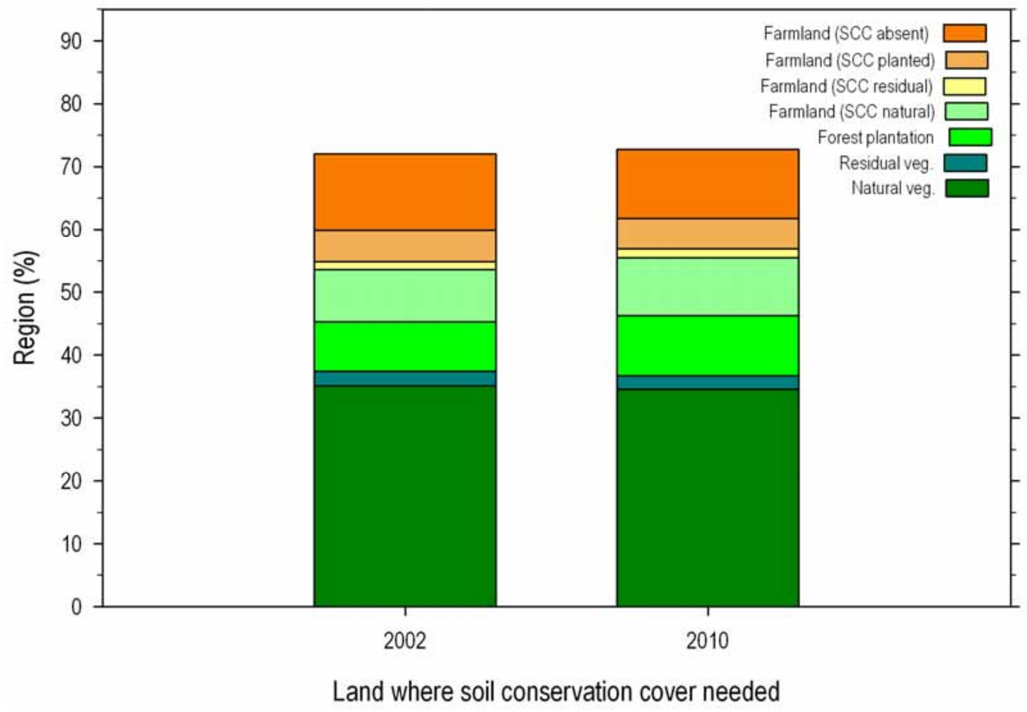

Figure 5.16: Extent of soil conservation cover (SCC) in the Wellington region as determined from point survey analyses of aerial photographs taken in 2002 and 2010 (adapted from Crippen & Hicks 2011)

The other major changes in soil conservation cover were an increase in farmland with natural soil conservation cover and a decrease in the area of farmland which requires soil conservation cover but it is currently absent. This has resulted in an additional 8,900 hectares (approximately) of farmland (predominantly drystock pasture) having soil conservation cover since 2002, either through farmland being retired so that native vegetation regenerates, or farmland on erosion-prone surfaces being planted with forestry or poplar and willow tree poles.

The amount of bare soil exposed amongst soil conservation covers is a measure of the effectiveness of how well or otherwise the cover is protecting the soil against erosion caused by natural processes. Between 2002 and 2010 there was a decrease in bare soil caused by natural processes amongst most types of soil conservation cover (Figure 5.17). This includes the amount of bare soil on farmland which decreased from 0.24% of the region (approximately 1,950 ha) in 2002 to 0.17% of the region (approximately 1,380 ha) in 2010. Amongst natural vegetation there was also a decrease of approximately 240 ha (0.03% of the region) in bare soil. The bare soil amongst natural vegetation remains quite high, simply because it is present on Wellington's steepest and most unstable land – the mountain ranges – where geological and climatic factors ensure ongoing erosion (Crippen & Hicks 2011).

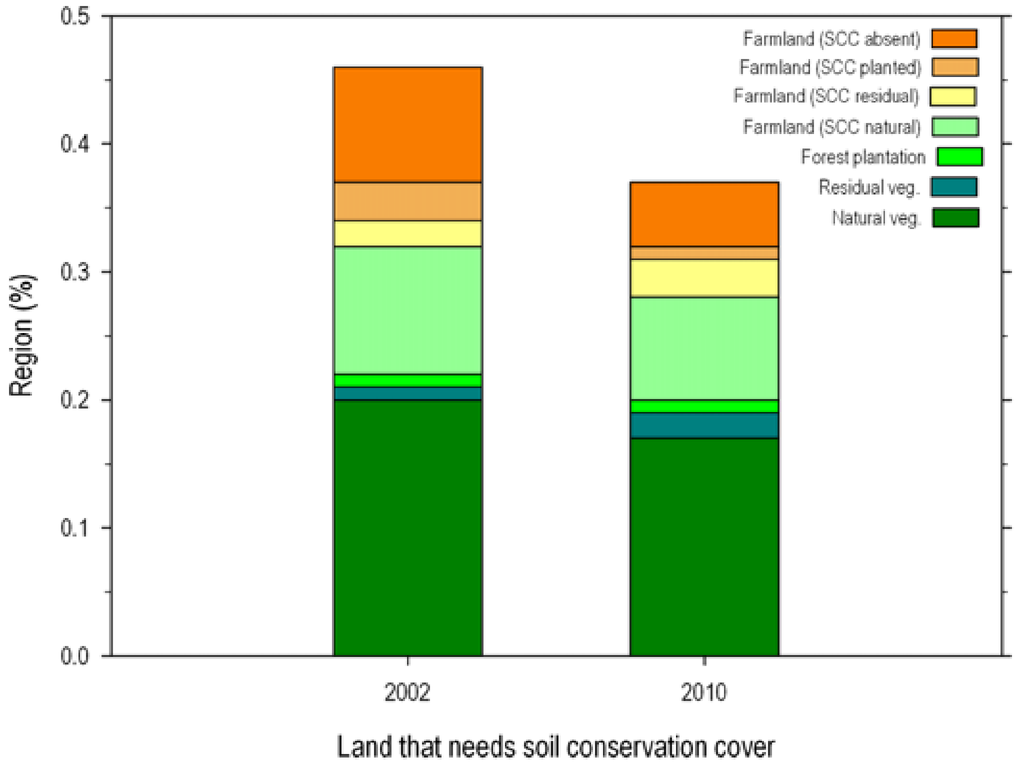

Figure 5.17: Extent of bare soil caused by natural processes according to soil conservation cover (SCC) in the Wellington region as determined from point survey analyses of aerial photographs taken in 2002 and 2010 (adapted from Crippen & Hicks 2011)

5.3 Synthesis

Statistically significant changes were found in the mean values of some soil quality indicators at both dairy farm and vegetable growing sites sampled on three occasions between 2000 and 2010. At dairy farm sites, there were significant increases in Olsen P, total nitrogen, AMN and total recoverable cadmium concentrations over the three sampling events. Macroporosity also increased significantly over time; although this is a positive or improving trend, overall, the values are still consistently low – a large proportion of sites have consistently recorded values below the lower threshold of the target range every year of sampling, indicating soil compaction is an issue at the dairy farm sites. While soil cadmium concentrations are not currently at levels of immediate concern, the increase in mean concentration across the three surveys suggests accumulation of cadmium in dairy farm soils is a potential emerging issue.

At the vegetable growing sites, the mean C:N ratio value decreased significantly over the three sampling events, while mean anaerobic mineralisable nitrogen (AMN) concentrations increased. The latter is considered an improving trend given AMN concentrations across many sites are only just within the lower threshold of the target range. Although no statistically significant changes were observed in the mean values of other soil quality indicators between 2000 and 2010, many of the other indicators returned poor results across all three sampling events; Olsen P levels remain high, total carbon and total nitrogen levels are consistently low, and soil structure is poor (low macroporosity and very low aggregate stability).

Analysis of aerial photographs indicates that there was a slight increase in stable and erosion-prone land surfaces across the Wellington region between 2002 and 2010, mainly due to the re-vegetation of some former erosion scars. However, soil disturbance caused by land use activities increased by approximately 24,000 ha across the region, mainly as a result of farm and forest tracking, cultivation and spraying for pasture renewal. Only a small percentage of disturbed surfaces created bare soil across the region, however, between 2002 and 2010 the amount of bare soil caused by cropping and horticulture as well as dairy farming increased; in contrast, the amount of bare soil caused by drystock farming decreased.

The steep landscape of the Wellington region means that soil conservation cover is needed across much of it. The percentage of the region which has some form of soil conservation cover increased from 59.9% in 2002 to 61.7% in 2010 (approximately 14,600 ha). This increase in soil conservation cover is predominantly the result of an additional 13,800 ha of forest plantations, but also an additional 8,900 hectares of farmland (mainly drystock pasture) having soil conservation cover since 2002 – either through farmland being retired so that native vegetation regenerates, or farmland on erosion-prone surfaces being planted with forestry or poplar and willow tree poles. Very small amounts of bare soil were created when soil conservation cover was present in both 2002 and 2010.

6. Discussion

This section discusses the main findings from Sections 4 and 5, highlighting the key soil quality and stability issues for the Wellington region (and placing these in a national context where possible). Firstly, it begins by looking at the impacts of land use on soil quality, and specifically the potential impacts on production and risks to the surrounding environment. The second part of this section examines the stability of land surfaces across the region, the land use activities responsible for soil disturbance, and discusses the presence and effectiveness of soil conservation covers in reducing soil erosion in the hill country areas of the region. Finally, some best management practices for maintaining and improving soil health are outlined, along with some of the shortcomings associated with Greater Wellington's existing soil monitoring programmes.

6.1 Soil quality

6.1.1 Regional overview

Soil quality monitoring over the period 2000 to 2010 has shown that vegetable growing and dairy farming are the two land uses that have had the most impact on soil quality in the Wellington region, particularly around the Otaki area (Figure 6.1). The soils surrounding Otaki are considered some of the best in the region in terms of land use capability, which is why they support many of the more intensive land uses such as vegetable growing, dairy farming and horticulture. However, soil monitoring results to date indicate that these land uses are having an impact on soil quality, and changes to land use practices may be required to ensure these land uses are sustainable in the future.

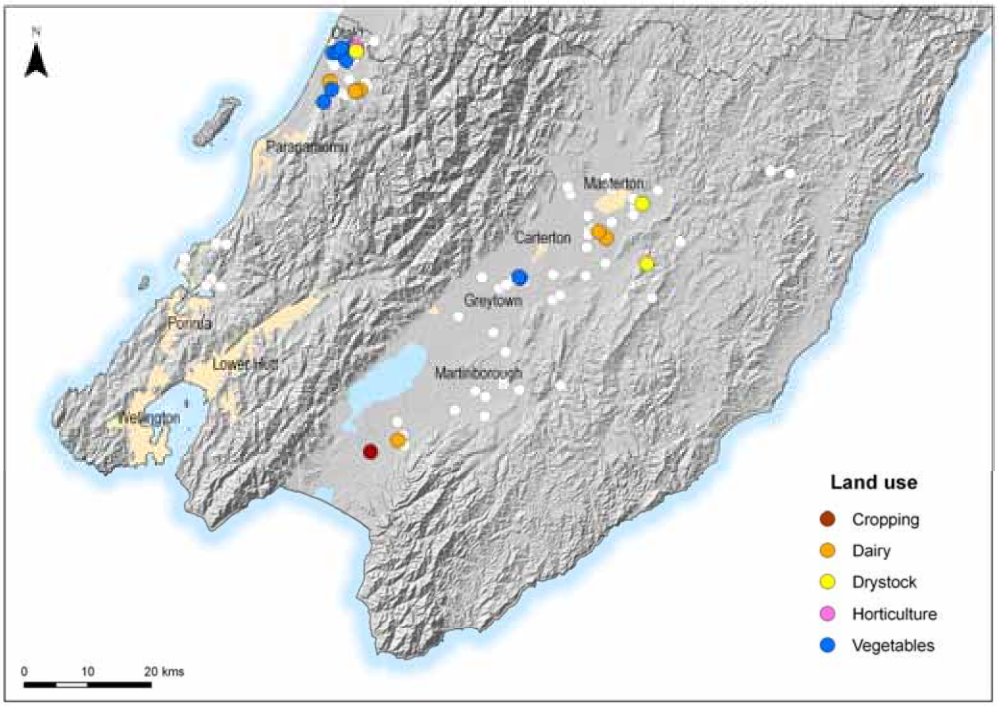

Figure 6.1: Soil quality monitoring sites with results outside the target range for two or more soil quality indicators (coloured circles), or less than two soil quality indicators (white circles) based on the most recent round of soil sampling

(a) Vegetable growing

Growing vegetables can have a range of impacts on soil quality (Figure 6.2), often dependent on specific management practices and the types of crops grown. Results from samples taken in 2000–04, 2006–07 and 2010 show soils at a majority of the vegetable growing sites had consistently low soil carbon and high Olsen P concentrations. The physical properties of the soil at the vegetable growing sites were also consistently found to be in poor condition, with low macroporosity and reduced soil aggregate stability. Nitrogen (the other essential nutrient for plant growth), and anaerobic mineralisable nitrogen (AMN) levels were relatively low across the vegetable growing sites.

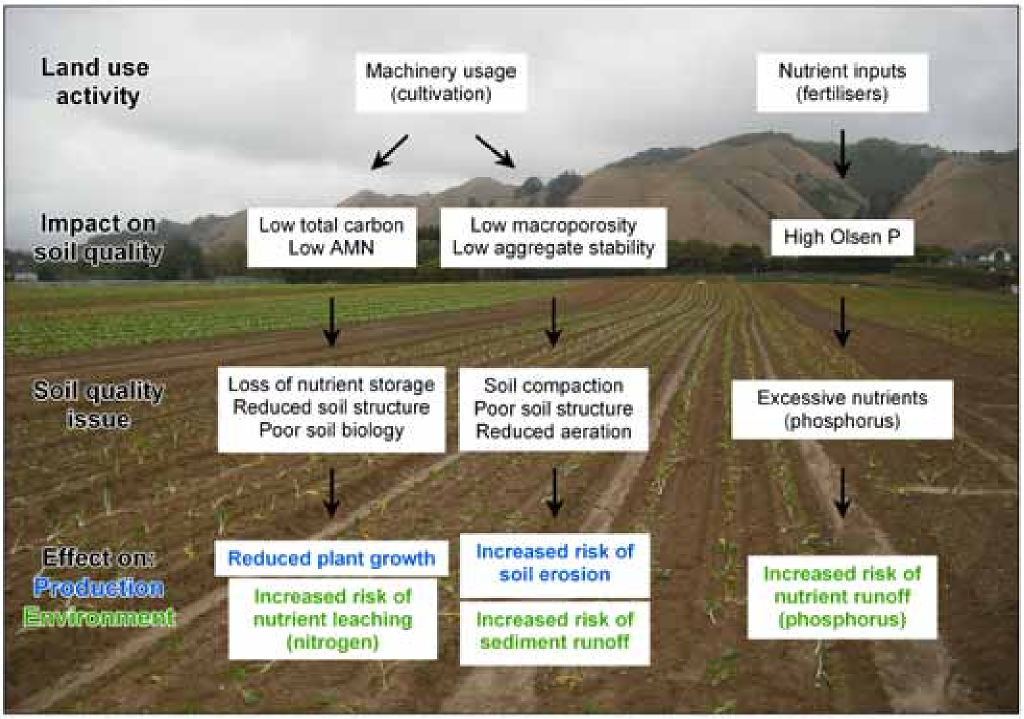

Figure 6.2: A simplified diagram showing the land use activities, impacts on soil quality, and the potential effects on production and the environment for a typical vegetable growing site in the Wellington region, as indicated from the results of Greater Wellington's soil quality monitoring programme

Although management practices for each individual monitoring site are not available, the monitoring results suggest that cultivation and rate of fertiliser application are having a negative impact on soil properties of the vegetable growing sites. It is widely recognised that intensive cultivation can lead to a considerable reduction in soil organic matter and carbon through increasing the rate of organic matter decomposition in soil, reducing inputs of organic residues to the soil each year and increasing aeration (oxidation) of the soil (McLaren & Cameron 1996). In addition, intensive cultivation can impact on the physical quality and structure of the soil by causing compaction, reducing the number of macropores and reducing the size of aggregates. Loss of soil structure can have serious consequences as weakly structured soils are likely to form a surface crust after heavy rainfall, and are easily eroded by wind or water (McLaren & Cameron 1996).

Nutrient inputs (both nitrogen and phosphorus) – through application of fertilisers – can be high at vegetable growing sites, but are dependent on the crop type grown. For example, fertilisers high in nitrogen are good for leaf and stem vegetables, while fertilisers high in phosphorus are more beneficial to root vegetables. Greater Wellington's soil monitoring results to date suggest that phosphorus inputs at the vegetable growing sites are high, and phosphate fertiliser application rates may be excessive.

Soils with poor soil structure and depleted soil carbon can have an impact on the environment due to the potential for nutrients to enter ground and surface waters. Phosphorus is predominantly bound to sediment, so there is an increased risk of phosphorus contaminating surface water through erosion, and overland flow if soils are also compacted. In contrast, nitrogen is generally more mobile, so there is an increased risk of nitrogen leaching through the soil profile into groundwater. Croplands are recognised as being very susceptible to erosion because their soil is repeatedly tilled and left without a protective cover of vegetation (Pimentel et al. 1995). The loss of crop cover is a particularly important issue that can leave bare soil exposed to the erosive force of rain drop impacts (Monaghan et al. 2010). Losses of phosphorus from vegetable growing sites in New Zealand is not well documented, but Haygarth and Jarvis (1999) reported losses of phosphorus in surface runoff from tilled or cropped land ranging between 0.1 and 6.2 kg P/ha/year in Ohio (United States). Given the degraded soil structure and enrichment of phosphorus in the topsoil of the vegetable growing sites in the Wellington region, the risk of phosphorus entering and contaminating waterways near these sites is considered to be high.

Low levels of soil carbon caused by overcultivation directly impact on soil structure, but also reduces the ability of the soil to store nutrients, particularly nitrogen. McLaren and Cameron (1996) noted that when soil carbon levels are low soil structural problems can occur, and nutritional problems such as a lack of adequate nitrogen and sulphur may arise. Monaghan et al. (2010) highlighted that intensive field vegetable production systems have the potential to lose very large amounts of nitrogen via nitrate leaching due to the ample quantities of fertiliser which are often used to grow the crop and the large amounts of nitrogen that can be left behind in crop residues. Although not specific to vegetable growing sites, nitrate concentrations in groundwater around Otaki have been found to be consistently elevated (Jones & Baker 2005; Tidswell 2009). Nitrogen levels in the soil were not particularly elevated at the vegetable growing sites, although this could be due to the very low levels of soil carbon reducing the storage ability of the soil; any nitrogen added to the soil and not taken up by the plants is very susceptible to being leached through the soil profile.

The soil quality issues outlined above not only have an effect on the environment, but can also affect production. McLaren and Cameron (1996) state that the effects of poor soil structure and compaction on drainage, aeration and plant root growth all eventually lead to a reduction in crop yield. The economic effects of poor soil quality are not restricted to loss of production; significant amounts of money can be lost by applying fertiliser when nutrient levels in the soil are already sufficient and there are ongoing costs associated with losing fertile topsoil through erosion.

(b) Dairy farming

Soil quality monitoring has also identified several issues across the dairy farm sites. These issues, the farm management practices which may have caused them, and the potential effects on production and the environment are summarised in Figure 6.3.

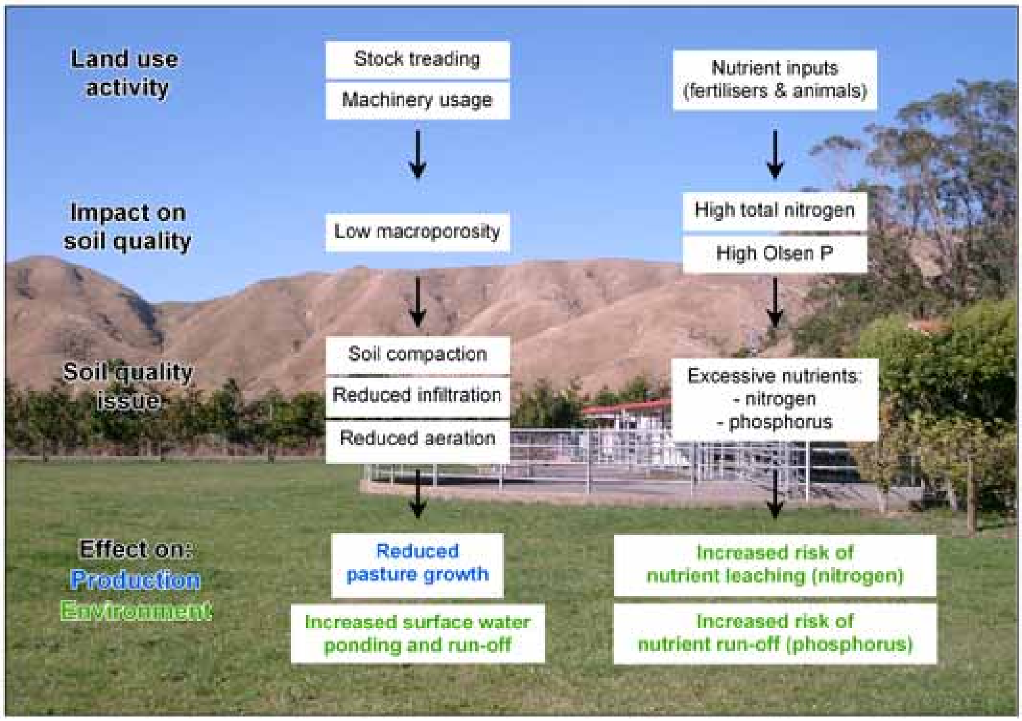

Figure 6.3: A simplified diagram showing the land use activities, impacts on soil quality, and the potential effects on production and the environment for a typical dairy farm site in the Wellington region, as indicated from the results of Greater Wellington's soil quality monitoring programme

The results from Greater Wellington's most recent round of soil quality monitoring on dairy farm sites (2009) found that nutrient concentrations (phosphorus and nitrogen) were elevated on a number of sites. Since the first soil samples were taken in 2000–04, Olsen P, total nitrogen and AMN concentrations have increased significantly, with a number of sites having concentrations above the upper threshold value in each year of sampling. In addition, macroporosity values have been consistently low across the dairy farm sites. The median macroporosity value of all the sites (although it has improved slightly) has been below the lower threshold value of the target range across all three sampling rounds (i.e., indicating soils are compacted).

While the reasons for individual sampling results are unknown – as specific land management information is difficult to obtain – the results indicate that nutrient inputs (both nitrogen and phosphorus) at the dairy farm sites are high (and at some sites excessive), and soils are being impacted by compaction. Nutrients are applied on most farms through fertilisers and dairy shed effluent (DSE), however, the majority of nutrients are excreted in dung or urine (Monaghan et al. 2010; (Stenger et al. 2009). Longhurst et al. (2000) also found that between 1977 and 1997 the mean nitrogen concentration of DSE doubled due to the volume of wash water used per cow proportionally decreasing as herd sizes increased. Therefore, the high nutrient levels found in the soils is likely to be directly from an increase in the amount of effluent, both from the dairy shed and animal excretions (principally urine in the case of nitrogen), and possibly increases in the amounts of fertilisers used to sustain pasture growth for increasing herd sizes. Information presented in Section 3.3 shows that dairy cattle numbers and stocking rates have increased across the Wellington region. This is likely to have had an impact on macroporosity and soil compaction, along with other factors such as grazing on wet soils, and machinery usage.

The primary issue of excessive nutrients in soil is the increased risk of nutrients entering waterways (although landowners can also be directly affected by spending considerable amounts of money on fertilisers when nutrient levels in the soil are already sufficient for pasture growth). Research shows that subsurface drainage is the main pathway of nitrogen transfer from agricultural land to water, with nitrate accounting for between 80-90% of the dissolved nitrogen discharged in drainage (Monaghan et al. 2010). In contrast, phosphorus losses from intensively grazed pastures arise from dissolution and loss of particulate material from the soil, washing-off of phosphorus from recently grazed pasture plants, dung deposits and fertiliser additions (McDowell et al. 2004). Therefore, where soils contain high levels of nitrogen there is an increased risk of nitrogen leaching through the soil into underlying groundwater, and where soils have high levels of phosphorus there is an increased risk of phosphorus entering surface water through run-off and overland flow. This appears to be occurring in the Mangatarere catchment near Carterton; intensive monitoring by Greater Wellington over 2008 and 2009 found elevated nitrogen in shallow groundwater, with the highest concentrations found downgradient of intensive piggery and dairy farm sites (Milne et al. 2010). In the same study, the majority of phosphorus in surface water samples was found to be bound to sediment, and it was identified that the main source of phosphorus to the Mangatarere Stream and its tributaries was likely to be overland flow (surface runoff) or stream bank sediment as a result of stock damage and/or erosion during high flows.

In addition to the issue of excessive nutrients, grazing large animals on wet soils, over stocking and use of machinery reduces macroporosity creating the issue of soil compaction, which reduces aeration and soil drainage. This can lead to an increase in gaseous losses of carbon and nitrogen, and reduced production caused by less root and plant growth (Mackay et al. 2006). Drewry and Paton (2000) found under dairy grazing an average macroporosity of 8% was associated with 81% of maximum pasture yield, and a similar study by Drewry et al. (2001) found that at 5% and 10% macroporosity the relative yield was 75% and 85% of maximum, respectively. The median macroporosity across the 21 dairy farm sites sampled was 6.6% in 2000-04, 8.8% in 2006/07 and 8.7% in 2009, suggesting that pasture production is being reduced across the region because of soil compaction. Waikato Regional Council (2010) estimated that pastoral farms were likely to have pasture yields as much as 20% lower than optimum as a result of compaction and treading, and it could be costing the Waikato region up to $200 million a year due to lost production.

A reduction in surface water infiltration and drainage can also result in increased surface water run-off (via overland flow), which can adversely affect the environment, particularly if the soil contains elevated nutrients. Milne et al. (2010) identified poorly drained soils that were compacted were likely to be a significant source of sediment-bound phosphorus to surface water in the lower Mangatarere catchment due to the reduced drainage ability of the soil and increased risk of overland flow.

An emerging issue for New Zealand rural soils is cadmium enrichment associated with the use of phosphate fertiliser. Regions throughout New Zealand with intensive agriculture and associated intensive phosphate fertiliser use tend to have higher cadmium loadings and soil concentrations (MAF 2011). While Greater Wellington's soil quality monitoring results to date indicate that current soil cadmium concentrations are generally below guideline levels and considered satisfactory, the median cadmium concentration across the 21 dairy farm sites increased from 0.35 mg/kg to 0.50 mg/kg over the three sampling events. If cadmium concentrations continue to accumulate at this rate cadmium accumulation in soils could become an issue for the region within 10–15 years. Although Olsen P concentrations were also high at the vegetable growing sites, cadmium concentrations were not elevated at these sites. This is believed to be due to other fertilisers with lower cadmium contents such as diammonium phosphate (DAP) being more commonly applied to vegetable growing sites compared to superphosphate which is the fertiliser predominantly used on pastoral land.

6.1.2 National context

In general, Greater Wellington's soil monitoring results to date mirror monitoring results across New Zealand reported in Sparling and Schipper (2004) and Ministry for the Environment (2007), which found widespread but moderate compaction under pastures and mixed cropping (which includes vegetables), depletion of total carbon under mixed cropping and nutrient imbalances (usually excess Olsen P) under mixed cropping and dairy pastures. However, Olsen P concentrations appear to be particularly high in the Wellington region compared to elsewhere. The median Olsen P concentrations (from the most recent round of soil sampling) at the dairy farm sites and vegetable growing sites throughout the Wellington region were 69 mg/kg and 117 mg/kg, respectively, significantly greater than the median Olsen P concentration of 44 mg/kg reported in Sparling & Schipper (2004) for soils under dairy pasture and mixed cropping (including vegetables) throughout New Zealand.

Soil quality is also monitored periodically by several other regional councils. The results presented in this report are similar to findings reported by Auckland Council (Stevenson 2010), Marlborough District Council (Gray 2010), Waikato Regional Council (Taylor 2011a) and Bay of Plenty Regional Council (Guinto 2009); soils under intensive land uses, particularly dairy farms and cropping (including vegetables), are having the most impact on soil quality.

6.2 Soil stability, disturbance and soil conservation cover

6.2.1 Regional overview

Over 54% of the Wellington region is classified as hill country in Crippen and Hicks (2011), making soil erosion an important regional issue. Soil erosion resulting in bare soil can be caused by both natural processes and land use activities, which can potentially reduce the on-site productive capability of the land, and also impact on the environment if the eroded soil enters water bodies such as rivers, lakes and wetlands. Information on production losses due to soil erosion is essential for quantifying bio-physical and economic impacts of mass movement erosion and to assess the sustainability of land use in New Zealand hill country (Rosser & Ross 2011). Soil disturbance and resulting bare soil on susceptible land surfaces can be reduced using soil conservation cover, such as woody vegetation, which can provide a stabilising effect if it is sufficiently dense to exert various root re-enforcements and de-watering effects (Crippen & Hicks 2011).

The results of regional soil stability surveys undertaken in 2002 and 2010 showed that the majority of the region's soil is intact, with a slight increase in stable and erosion-prone (inactive) land surfaces across the region over this period; this is mainly due to the re-vegetation of some former erosion scars. However, soil disturbance caused by land use activities increased by approximately 24,000 ha across the region since 2002. Land use activities which caused the most soil disturbance in 2010 included farm and forest tracking, cultivation, spraying for pasture renewal and grazing pressure. Although only a small percentage of disturbed surfaces have created bare soil across the region, between 2002 and 2010 the amount of bare soil caused by cropping and horticulture and, to a lesser extent, dairy farming, increased. In contrast, there was a significant decrease in the amount of bare soil caused by drystock farming – although it was still the largest contributing land use of bare soil in 2010 (owing mainly to it representing the dominant land use in hill country areas of the region). Land use activities such as cultivation and grazing on saturated soils can disturb stable land surfaces and create bare soil (Figure 6.4), although bare soil is predominantly created on hillsides through erosion and landslides (Figure 6.5).

Bare soil on relatively flat and stable land is generally smaller in scale and relates to specific land use activities (such as tracking and grazing pressure) compared to bare soil on hill country caused by erosion which can be much more widespread. The effects of bare soil on flat land are also more localised, but the soil can still be damaged by compaction or lost through erosion, affecting production and nearby waterways.

(Source: Greater Wellington Environmental Regulation Department)

Figure 6.4: Cattle grazing on saturated soils in the Mangaroa Valley, disturbing the soil and creating a significant amount of bare soil. Also note the pugging and compaction of the soil at hock depth.

(Source: Greater Wellington Land Management Department)

Figure 6.5: Much of the hill country in the Wellington region is susceptible to erosion, as shown in this photo of an area of eastern Wairarapa after a large rainfall event in July 2006. Note where soil conservation cover has been planted, soil erosion is less prominent.

The on and off-site economic, environmental and social impacts of shallow landslides can be very significant, including one or more of: pollution of waterways, damage to roads, buildings and other infrastructure, social upheaval, and displacement, reduced revenue and cost of reinstatement (Douglas et al. 2011). Also, erosion debris causes rivers to become filled in with silts and gravels, increasing the risk of flooding, and contributing to water quality problems such as loss of aquatic habitat and increased sediment loads (Ministry for the Environment 2007). Environmental effects such as sedimentation in streams and estuaries as a result of landslides throughout the region are not widely reported, but the effect on production and soil properties from historic erosion scars has been well documented (Lambert et al. 1984); Rosser & Ross 2011; Douglas et al. 2011). Reduction in land production from soil erosion occurs directly through the loss of topsoil and indirectly through reduced pasture yields on eroded ground (Rosser & Ross 2011). A trial conducted in the Wairarapa by Lambert et al. (1984) found that pasture dry matter yields on young slip scars were approximately 20% of the yields produced on uneroded ground, and while such scars re-vegetated rapidly over the first 20 years and could attain 70-80% of the original production, further recovery was slow and complete recovery was considered unlikely to occur. Shallow landslides also have immediate effects including loss of pasture, reduced soil nutrient status and lowered organic matter content and water holding capacity (Douglas et al. 2011).

Woody vegetation (soil conservation cover), especially spaced-planted trees, is used widely in New Zealand to reduce the occurrence of shallow landslides on pastoral hill country. Crippen and Hicks (2011) (summarised in Section 5.2.4 of this report) found the percentage of the Wellington region which has some form of soil conservation cover has increased over recent years, predominantly as a result of over 13,800 ha of forest plantations, but also an additional 8,900 ha of farmland (predominantly drystock pasture) being retired so that native vegetation is able to regenerate, or farmland being planted with forestry or soil conservation poles. The bare soil percentages for farmland and forest plantations were not large in 2002 or 2010, reflecting that these land uses are carried out just in part on unstable land and also that fresh erosion either has been minimal or has quickly re-vegetated between the 2002 and 2010 surveys. Given that a large storm affected much of the hill country in February 2004 and July 2006, the latter explanation is more likely (Crippen & Hicks 2011).

Of the farmland in the region that requires some form of soil conservation cover, 58% currently has it, but a further 42% (approximately 89,300 ha) still requires some form of protection against erosion. This indicates a significant amount of farmland needs to be either allowed to regenerate, or be supplemented with soil conservation covers in the form of soil conservation pole plantings.

6.2.2 National context

The North Island’s east coast is particularly susceptible to soil erosion due to factors such as steep landscapes, soft and erodible underlying geology, climate and the removal of soil conservation cover. This soil erosion problem is unique in that the magnitude of the problem is far greater than elsewhere in New

Zealand (Ministry for the Environment 2007). The Ministry for the Environment (2007) lists the Wellington region as one of the regions in New Zealand with large areas of erosion-prone hill country.

Soil stability (intactness and disturbance) is monitored by several other regional councils using the established monitoring procedure documented in Burton et al. (2009), but because soil erosion is generally dependent on regional landscape, geology and climatic factors, it is difficult to make comparisons with other regions. However, there are some similarities between the surveys undertaken in the Wellington region and the Waikato region in terms of impacts from land use activities. Thompson and Hicks (2009) reported there was an increase in soil bared by cultivation, pasture renewal and tracking in the Waikato region between 2002 and 2007. However, they note that after cross-checking the aerial photographs, the increase in bare soil was possibly due to the 2007 photographs being taken earlier in the cultivation cycle, when more soil was visible amongst freshly sown crops; further, on dairy and drystock farms, the increased bare soil was also possibly due to timing of 2007 photography which detected spring cultivation for pasture renewal. Cross-checking between the years of photography was not undertaken by Crippen and Hicks (2011), so this could also be relevant for the Wellington region.

6.3 Sustainable land management practices

The results from Greater Wellington’s soil quality monitoring and soil stability surveys demonstrate that the more intensive land uses such as vegetable growing and dairy farming are having the most impact on soil quality, while pastoral hill country remains the most susceptible land to soil erosion. This indicates that particular land management practices may not be sustainable in the future. Substantial research has been undertaken throughout New Zealand on sustainable land management practices, particularly with regard to nutrient management (McKergow et al. 2008; Monaghan et al. 2009; Monaghan et al. 2010). This section touches briefly on these sustainable land use practices which can be used to maintain or improve soil health and reduce both the economic and environmental effects that arise from production on poor quality soils.

As outlined previously in this report, while nutrients are critical for sustaining optimal plant growth, if soils contain excessive levels of nutrients there is an increased risk of nutrients entering groundwater or surface water, and there is also the economic cost of unnecessarily buying and applying fertiliser. Nutrient budget tools such as OVERSEER® can be used to assess all on-farm nutrient inputs (animal effluent, fertiliser and feed) and nutrient outputs (leaching, run-off and volatilisation) to ensure soil nutrients are kept at optimum levels and there is minimal risk of excessive nitrogen loss to underlying groundwater. Nitrification inhibitors (ie, chemicals that inhibit the transformation of ammonium to nitrate in the soil) can also be used to reduce nitrogen leaching. In contrast to nitrate, ammonium is more readily retained in the soil, and thus nitrification inhibitors can help to decrease losses of nitrate in drainage water (Monaghan et al. 2010).

Low macroporosity (compaction) is another significant issue and is usually caused by animal treading and machinery usage. Best management practices to improve macroporosity on dairy farms involve minimising wet soil damage through pugging by ensuring cows are moved to feedpads or yards when soils are waterlogged (Bewsell & Kaine 2005). Reduced grazing intensity, stock exclusion for 2.5 years and reduced grazing practices can also improve the physical condition of soils due to biological activity, wetting and drying cycles, earthworm and root activity and the absence of grazing (Drewry & Paton 2000). At vegetable growing sites, the physical condition of the soil can be improved by minimising cultivation and machinery use and rotating crops to ensure crop cover protection of bare soil.

Various forms of management practices can be used to avoid losses of soil carbon or improve soil carbon levels, however, building up organic matter and carbon in soils is a slow process. The traditional approach to maintaining soil organic matter and carbon levels is to alternate periods of cropping with periods in which the soil is sown down to grass or grass/clover pastures, known as crop rotation (McLaren & Cameron 1996).

Woody vegetation, especially spaced-planted trees, is used widely in New Zealand to reduce the occurrence of shallow landslides on pastoral hill country (Douglas et al. 2011). Other sustainable land use practices for reducing soil erosion include retiring land and allowing native vegetation to regenerate, or converting pastoral land into plantation forestry. The benefit of incorporating spaced trees into hill pastoral systems is it enables the continuation of livestock farming enterprises on these fragile landscapes (Douglas et al. 2011).

Other sustainable land management practices can be used to reduce the effects of intensive land use on poor soil quality, but do not directly maintain or improve soil quality or stability. Excluding stock from streams, riparian plantings and ensuring sufficient effluent storage can all reduce the risk of soil and nutrients entering waterways. Monaghan et al. (2010) also suggest that contour ploughing is a simple precaution that can help decrease runoff and therefore the risk of phosphorus loss at vegetable growing sites.

6.4 Monitoring limitations

Greater Wellington’s soil monitoring programmes provide valuable information on soil health in the Wellington region. However, while monitoring to date has identified several issues and trends in terms of soil quality and stability across the region, there are a number of limitations with the existing monitoring programmes:

- The number of soil quality monitoring sites for some land use categories is limited. Ideally, the sample size (number of sites) for each land use category should be approximately 25–30 (Hill & Sparling 2009). Consideration should be given to increasing the number of sites monitored for some of the more intensive land uses, such as vegetable growing, or the amalgamation of land use categories, such as cropping and horticulture. Change in land use can also affect the number of sites in each land use category. Additional sites may need to be added as some sites are converted from one land use to another, especially when sites are converted into residential developments and can no longer be sampled.

- Not all the high value soils and intensive land use areas of the Wellington region are currently represented by the soil quality monitoring programme. For example, the Mangaroa Valley in Upper Hutt contains some of the region’s more versatile soils, and intensive land uses, including dairy farming, are undertaken in the area. A review is warranted of the existing monitoring site network to ensure there is full spatial representation of the region’s high value soils under intensive land uses.

- Interpretation of soil quality results remains difficult without accurate site specific land management information. Currently landowners of soil quality monitoring sites are sent questionnaires prior to sampling to obtain information on things such as fertiliser usage and stocking rates. However, completion rates of these questionnaires are not high, and information presented is often not of much direct use in assessing the soil condition. The questionnaires may need to be improved or another method of collecting land information may need to be investigated.

- The results of the soil stability surveys are often dependent on the timing and availability of aerial photography, which needs to be taken into account during analysis. Future surveys should also ensure that cross-checking is undertaken to evaluate the impact of the timing and quality of photography between survey dates.

7. Conclusions

Soil quality monitoring across the Wellington region over 2000 to 2010 shows that the soils at most monitoring sites are in a reasonable condition. However, some land uses, notably vegetable growing and dairy farming, are clearly impacting on soil quality, particularly in and around Otaki.

Vegetable growing sites recorded the poorest soil quality results of all of the land uses monitored. The results at many sites indicate intensive cultivation has reduced soil carbon to low levels, degraded soil structure and compacted soils, while continued fertiliser usage has resulted in very high levels of Olsen P in the soil. In combination, these soil conditions increase the risk of soil and nutrients entering ground and surface waters (particularly phosphorus), and potentially, negatively impact on production.

Dairy farm sites also had significant soil quality issues, primarily compaction due to low macroporosity across most of the sites. Very high concentrations of nutrients (both nitrogen and Olsen P) were found in the soils at some sites, and the highest concentrations of cadmium out of all the land uses were found at the dairy farm sites. These issues are likely to have been caused by grazing animals on wet soils, high stocking rates and high inputs of nutrients from both animals and fertilisers (superphosphate). Compacted soils have a direct impact on pasture growth and overall production, while elevated concentrations of nutrients in the soil increase the risk of nutrients entering ground and surface waters.

While few statistically significant changes were found in the mean values of soil quality indicators at vegetable growing sites sampled on three occasions between 2000 and 2010, at dairy farm sites, there were significant increases in Olsen P, total nitrogen, anaerobic mineralisable nitrogen and total recoverable cadmium concentrations over the three sampling events. Macroporosity also increased significantly over time; although this is a positive or improving trend, overall, the values remain consistently low. Soil cadmium concentrations are not currently at levels of immediate concern but the increase in mean concentration across the three surveys suggests accumulation of cadmium in dairy farm soils needs to be monitored closely.

Of the other land use types monitored, drystock farm sites had similar issues to dairy farm sites, but to a lesser degree. Compaction was common, but both nitrogen and Olsen P concentrations were more variable; at some sites nutrient levels were too high and at others they were deficient. The impacts on soil quality at the horticulture and cropping sites were minimal (although sample sizes for these land uses are small) and the soil at the forestry sites showed no impacts from land use.

The results of regional soil stability surveys undertaken in 2002 and 2010 showed that the majority of the Wellington region's soil is intact, and there has been a slight increase in stable and inactive land surfaces due to the re-vegetation of some former erosion scars. However, soil disturbance caused by land use activities increased by approximately 24,000 ha across the region since 2002 with land use activities such as farm and forest tracking, cultivation, spraying for pasture renewal and grazing pressure causing most of the disturbance. Soil conservation in the form of woody vegetation remains important for the region due to the susceptibility of erosion in the hill country. Across the region, approximately 89,300 ha of land requires some form of protection against erosion. This indicates a significant amount of farmland still needs to be either allowed to regenerate, or be supplemented with soil conservation covers in the form of soil conservation pole plantings.

One final important issue is the loss of high quality soils. Throughout the Wellington region, high quality soils that are versatile and able to support intensive land uses such as vegetable growing and arable cropping are scarce. Since 1975, significant amounts of the region's most versatile soils and the production potential of those soils have been lost to urban development, particularly around urban centres such as Otaki.

7.1 Recommendations

1. Carry out a review of the existing soil quality monitoring programme to ensure that:

    - The number of sites monitored under each land use category is sufficient to allow for the comprehensive and statistically robust analysis of monitoring information; and,

    - Monitoring sites represent all high quality soils of the region, particularly catchments that are known to be used for intensive land uses such as the Mangatarere and Mangaroa valleys.

2. Conduct another regional soil stability survey in 5–10 years time, with aerial photography programmed to allow the survey to be completed.

3. Take into account the findings of this report in the review of Greater Wellington's existing regional plans, particularly the issues around intensive land use impacts on soil quality and the loss of high quality soils. Particular consideration should be given to implementing measures that require nutrient budgeting to minimise the impacts of nutrient loss/export from intensive land uses such as vegetable growing and dairy farming.

4. Continue Greater Wellington's existing soil conservation programmes with landowners to reduce soil erosion across the region's erosion-prone hill country.

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Appendix 1: Soil quality monitoring site details

Table A1: Details of the soil quality monitoring sites in the Wellington region

Site	Land use	NZ Soil Classification	Soil type	Sample dates		
GW001	Horticulture	Typic Orthic Brown	Ashhurst stony silt loam	Nov-2000	-	-
GW002	Drystock	Typic Orthic Brown	Ashhurst stony silt loam	Nov-2000	Apr-2008	-
GW003*	Vegetables	Mottled Orthic Brown	Te Horo silt loam	Nov-2000	-	-
GW004	Horticulture	Mottled Orthic Brown	Te Horo silt loam	Nov-2000	-	-
GW005	Dairy	Acidic Allophanic Brown	Kawhatau stony silt loam	Nov-2000	Mar-2006	Apr-2009
GW006*	Dairy	Mottled Orthic Brown	Te Horo silt loam	Nov-2000	Mar-2006	-
GW007	Native forest	Mottled Orthic Brown	Te Horo silt loam	Nov-2000	-	-
GW008	Drystock	Mottled Orthic Brown	Te Horo silt loam	Nov-2000	Apr-2008	-
GW009	Native forest	Acidic Allophanic Brown	Kawhatau silt loam	Nov-2000	-	-
GW010	Dairy	Acidic-weathered Fluvial Recent	Manawatu fine sandy loam	Nov-2000	Mar-2006	Apr-2009
GW011	Native forest	Mottled Fluvial Recent	Rangitikei silt loam	Nov-2000	-	-
GW012	Drystock	Acidic Fluvial Recent	Rangitikei gravelly fine sandy loam	Nov-2000	Apr-2008	-
GW013**	Dairy	Typic Recent Gley	Ahikouka silt loam	Nov-2000	-	Apr-2009
GW014	Native forest	Typic Recent Gley	Ahikouka silt loam	Nov-2000	-	-
GW015	Dairy	Typic Recent Gley	Ahikouka silty clay	Nov-2000	Mar-2006	Apr-2009
GW016	Vegetables	Typic Recent Gley	Ahikouka clay loam	Nov-2000	Mar-2006	May-2010
GW017	Cropping	Argillic Perch-gley Pallic	Kokotau silt loam	Nov-2000	Mar-2006	May-2010
GW018	Drystock	Argillic Perch-gley Pallic	Kokotau silt loam	Nov-2000	Apr-2008	-
GW019	Dairy	Argillic Perch-gley Pallic	Kokotau silt loam	Nov-2000	Mar-2006	Apr-2009
GW020	Native forest	Argillic Perch-gley Pallic	Kokotau silt loam	Nov-2000	-	-
GW021	Cropping	Typic Recent Gley	Ahikouka clay loam	May-2001	Mar-2006	May-2010
GW022	Cropping	Acidic-weathered Fluvial Recent	Greytown silt loam	May-2001	Mar-2006	May-2010
GW023	Dairy	Acidic-weathered Fluvial Recent	Greytown silt loam	May-2001	Mar-2006	Apr-2009
GW024	Horticulture	Acidic-weathered Fluvial Recent	Greytown fine sandy loam	May-2001	-	-
GW025	Horticulture	Typic Recent Gley	Ahikouka silt loam	May-2001	-	-
GW026	Drystock	Acidic-weathered Fluvial Recent	Greytown silt loam	May-2001	Apr-2008	-

Site	Land use	NZ Soil Classification	Soil type	Sample dates		
GW027	Vegetables	Acidic-weathered Fluvial Recent	Manawatu very fine sandy loam	May-2001	Mar-2006	Apr-2010
GW028	Horticulture	Acidic-weathered Fluvial Recent	Manawatu shallow silt loam	May-2001	-	-
GW029	Native forest	Typic Perch-gley Pallic	Bideford silt loam	Dec-2001	-	-
GW030	Drystock	Mottled Immature Pallic	Martinborough loam	Dec-2001	Apr-2008	-
GW031	Cropping	Mottled Immature Pallic	Martinborough loam	Dec-2001	Mar-2006	May-2010
GW032	Dairy	Typic Perch-gley Pallic	Bideford silt loam	Dec-2001	Mar-2006	Apr-2009
GW033	Drystock	Typic Perch-gley Pallic	Bideford silt loam	Dec-2001	Apr-2008	-
GW034	Native forest	Typic Immature Pallic	Martinborough loamy silt	Dec-2001	-	-
GW035	Horticulture	Typic Immature Pallic	Martinborough silt loam	Dec-2001	-	-
GW036	Dairy	Typic Perch-gley Pallic	Moroa silt loam	Dec-2001	Mar-2006	Apr-2009
GW037	Drystock	Typic Argillic Pallic	Tauherenikau silt loam	Dec-2001	Apr-2008	-
GW038	Dairy	Typic Argillic Pallic	Tauherenikau silt loam	Dec-2001	Mar-2006	Apr-2009
GW039	Native forest	Mottled Fluvial Recent	Rangitikei loamy silt	Dec-2001	-	-
GW040*	Drystock	Pedal Immature Pallic	Moroa silt loam	Dec-2001	-	-
GW041	Horticulture	Typic Immature Pallic	Tauherenikau gravelly sandy loam	Dec-2001	-	-
GW042	Dairy	Typic Immature Pallic	Moroa silt loam	Dec-2001	Mar-2006	Apr-2009
GW043	Drystock	Mottled Fluvial Recent	Manawatu silt loam	Apr-2002	Apr-2008	-
GW044	Vegetables	Mottled Orthic Brown	Rahui silt loam	Apr-2002	Mar-2006	Apr-2010
GW045	Native forest	Mottled Orthic Brown	Rahui silt loam	Apr-2002	-	-
GW046	Dairy	Acidic Orthic Gley	Rahui silt loam	Apr-2002	Mar-2006	Apr-2009
GW047	Horticulture	Acidic Orthic Gley	Rahui silt loam	Apr-2002	-	-
GW048	Dairy	Acidic Fluvial Recent	Otaki gravelly silt loam	Apr-2002	Mar-2006	Apr-2009
GW049	Native forest	Typic Fluvial Recent	Manawatu silt loam	Apr-2002	-	-
GW050	Drystock	Acidic Orthic Gley	Rahui silt loam	Apr-2002	Apr-2008	-
GW051	Forestry	Pallic Orthic Brown	Paremata hill soils	Oct-2003	-	-
GW052	Native forest	Pallic Orthic Brown	Paremata hill soils	Oct-2003	-	-
GW053	Forestry	Typic Orthic Brown	Makara steepland soils	Oct-2003	-	-
GW054	Drystock	Typic Orthic Brown	Makara steepland soils	Oct-2003	Apr-2008	-
GW055	Forestry	Typic Firm Brown	Korokoro hill soils	Oct-2003	-	-
GW056	Drystock	Typic Firm Brown	Korokoro hill soils	Oct-2003	Apr-2008	-
GW057	Native forest	Typic Firm Brown	Korokoro hill soils	Oct-2003	-	-

Site	Land use	NZ Soil Classification	Soil type	Sample dates		
GW058	Drystock	Mottled Argillic Pallic	Paremata hill soils	Oct-2003	Apr-2008	-
GW059	Native forest	Typic Orthic Recent	Terawhiti steepland soils	Oct-2003	-	-
GW060	Drystock	Weathered Orthic Recent	Terawhiti steepland soils	Oct-2003	Apr-2008	-
GW061	Drystock	Mottled Orthic Brown	Tinui hill soils	Oct-2003	Apr-2008	-
GW062	Forestry	Typic Firm Brown	Tinui hill soils	Oct-2003	-	-
GW063*	Drystock	Weathered Rendzic Melanic	Kourarau hill soils	Oct-2003	-	-
GW064	Forestry	Weathered Rendzic Melanic	Kourarau hill soils	Oct-2003	-	-
GW065	Forestry	Mottled Argillic Pallic	Wharekaka hill soils	Oct-2003	-	-
GW066	Drystock	Mottled Argillic Pallic	Wharekaka hill soils	Oct-2003	Apr-2008	-
GW067	Forestry	Typic Orthic Recent	Wharoama steepland soils	Oct-2003	-	-
GW068	Drystock	Weathered Orthic Recent	Wharoama steepland soils	Oct-2003	Apr-2008	-
GW069	Forestry	Typic Orthic Recent	Taihape steepland soils	Oct-2003	-	-
GW070	Drystock	Weathered Orthic Recent	Taihape steepland soils	Oct-2003	Apr-2008	-
GW071	Cropping	Typic Recent Gley	Ahikouka silt loam	Apr-2004	Mar-2006	May-2010
GW072*	Cropping	Argillic Perch-gley Pallic	Kokotau silt loam	Apr-2004	-	-
GW073	Horticulture	Weathered Fluvial Recent	Greytown silt loam	Apr-2004	-	-
GW074	Horticulture	Typic Recent Gley	Ahikouka silt loam	Apr-2004	-	-
GW075	Vegetables	Weathered Fluvial Recent	Greytown silt loam	Apr-2004	Mar-2006	May-2010
GW076	Dairy	Mottled Immature Pallic	Tauherenikau silt loam	Apr-2004	Apr-2007	Apr-2009
GW077	Horticulture	Mottled Argillic Pallic	Kokotau silt loam	Apr-2004	-	-
GW078	Dairy	Weathered Fluvial Recent	Greytown silt loam	Apr-2004	Apr-2007	Apr-2009
GW079	Vegetables	Typic Recent Gley	Ahikouka silt loam	Apr-2004	Mar-2006	May-2010
GW080	Vegetables	Weathered Fluvial Recent	Greytown silt loam	Apr-2004	Mar-2006	May-2010
GW081	Horticulture	Weathered Fluvial Recent	Greytown silt loam	Apr-2004	-	-
GW082	Vegetables	Typic Recent Gley	Otukura stony silt loam	Apr-2004	Apr-2007	May-2010
GW083	Horticulture	Pallic Orthic Brown	Martinborough stony silt loam	Apr-2004	-	-
GW084*	Vegetables	Weathered Fluvial Recent	Greytown silt loam	Apr-2004	Apr-2007	-
GW085	Cropping	Typic Recent Gley	Ahikouka silt loam	Apr-2004	Mar-2006	May-2010
GW086	Cropping	Typic Recent Gley	Ahikouka silt loam	Apr-2004	Mar-2006	May-2010
GW087*	Vegetables	Weathered Fluvial Recent	Manawatu silt loam	Apr-2004	Apr-2007	-
GW088*	Vegetables	Weathered Fluvial Recent	Manawatu silt loam	Apr-2004	Apr-2007	-

Site	Land use	NZ Soil Classification	Soil type	Sample dates		
GW089	Horticulture	Typic Orthic Brown	Ashhurst stony silt loam	Apr-2004	-	-
GW090	Vegetables	Typic Orthic Brown	Te Horo silt loam	Apr-2004	Apr-2007	Apr-2007
GW091	Horticulture	Typic Orthic Gley	Kairanga silt loam	Apr-2004	-	-
GW092	Vegetables	Typic Orthic Gley	Kairanga silt loam	Apr-2004	Apr-2007	Apr-2010
GW093	Vegetables	Weathered Fluvial Recent	Manawatu silt loam	Apr-2004	Apr-2007	Apr-2010
GW094	Vegetables	Weathered Fluvial Recent	Manawatu silt loam	Apr-2004	Apr-2007	Apr-2010
GW095	Drystock	Weathered Fluvial Recent	Greytown silt loam	Oct-2004	Apr-2008	-
GW096	Dairy	Weathered Fluvial Recent	Greytown silt loam	Oct-2004	Apr-2007	Apr-2009
GW097	Dairy	Weathered Fluvial Recent	Greytown silt loam	Oct-2004	Apr-2007	Apr-2009
GW098	Dairy	Typic Perch-gley Pallic	Moroa silt loam	Oct-2004	Apr-2007	Apr-2009
GW099	Drystock	Mottled Immature Pallic	Kokotau silt loam	Oct-2004	Apr-2008	-
GW100**	Dairy	Mottled Argillic Pallic	Kokotau silt loam	Oct-2004	-	Apr-2009
GW101*	Vegetables	Mottled Argillic Pallic	Kokotau silt loam	Oct-2004	Apr-2007	-
GW102	Native forest	Weathered Orthic Recent	Greytown silt loam	Oct-2004	-	-
GW103	Dairy	Typic Immature Pallic	Tauherenikau gravelly silt loam	Oct-2004	Apr-2007	Apr-2009
GW104	Native forest	Typic Immature Pallic	Tauherenikau silt loam	Oct-2004	-	-
GW105	Dairy	Mottled Argillic Pallic	Kokotau silt loam	Oct-2004	Apr-2007	Apr-2009
GW106	Drystock	Weathered Orthic Recent	Greytown silt loam	Oct-2004	Apr-2008	-
GW107	Vegetables	Weathered Orthic Recent	Manawatu silt loam	Oct-2004	Apr-2007	Apr-2010
GW108	Vegetables	Typic Orthic Gley	Kairanga clay loam	Oct-2004	Apr-2007	Apr-2010
GW109	Dairy	Typic Orthic Brown	Ashhurst stony silt loam	Oct-2004	Apr-2007	Apr-2009
GW110	Native forest	Typic Orthic Brown	Ashhurst stony silt loam	Oct-2004	-	-
GW111	Vegetables	Typic Orthic Brown	Hautere clay loam	Oct-2004	Apr-2007	Apr-2010
GW112	Vegetables	Typic Immature Pallic	Shannon silt loam	Oct-2004	Apr-2007	Apr-2010
GW113	Native forest	Typic Orthic Allophanic	Kawhatau silt loam	Oct-2004	-	-
GW114	Drystock	Mottled Immature Pallic	Shannon silt loam	Oct-2004	Apr-2008	-
GW115	Dairy	Typic Orthic Brown	Te Horo silt loam	Oct-2004	Apr-2007	Apr-2009
GW116	Dairy	Acidic Orthic Brown	Hautere stony silt loam	Oct-2004	Apr-2007	Apr-2009
GW117*	Dairy	Mottled Orthic Brown	Te Horo silt loam	Oct-2004	Apr-2007	-
GW118	Drystock	Typic Orthic Brown	Te Horo stony silt loam	Oct-2004	Apr-2008	-

Appendix 2: Laboratory analytical methods

Soil chemistry and soil physics analyses summarised in this report were completed at the Landcare Research laboratories in Palmerston North. Trace element analyses were undertaken at R.J. Hills Laboratory in Hamilton, and aggregate stability analyses were undertaken by Plant & Food Research laboratory in Lincoln. Where necessary, samples were stored at 4°C until analysis.

Table A2.1: Analytical methods

Indicator	Method
Bulk density	Measured on a sub-sampled core dried at 105°C.
Macroporosity	Determined by drainage on pressure plates at –10 kPa.
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 <2 mm air dried soils for 30 mins with 0.5M $NaHCO_3$ at pH 8.5 and measuring the PO_4^{3-} concentration by the molybdenum blue method.
Trace elements	Total recoverable digestion. Nitric/hydrochloric acid digestion, USEPA 200.2.
Aggregate stability	Calculated from the mean weight diameters of aggregates remaining on 2 mm, 1mm and 0.5 mm sieves after wet sieving. If stones are present a stone correction is undertaken.

Appendix 3: Soil quality indicators

The physical condition of the soil is determined from the bulk density, macroporosity and aggregate stability of the soil. Bulk density and macroporosity are both measures of soil compaction. Bulk density is the weight of a standard volume of soil, while macroporosity[16] is a measure of the larger voids in the soil and indicates the ability of the soil to supply air and water to the roots (SINDI 2010). Compaction can be caused by either animal treading, the impact of heavy machinery, cultivation, the loss of organic matter and subsequent desiccation, or a combination of some of these factors. Compaction reduces the number of pores available for water and gas movement, aeration, root growth and distribution, and nutrient uptake. Therefore, compaction of soils can reduce productivity, while also potentially impacting the environment by increasing the risk or surface run-off during rainfall events.

Aggregate stability is a measure of soil structure. Soil aggregates need to be of a size, shape and packing that maintains the necessary soil porosity for roots to easily access air, water and nutrients (Beare et al. 2005). Soils with high aggregate stability are better able to withstand the degradation that may result from cultivation, compaction and raindrop impact. Aggregates with low structural stability are more prone to dispersion by wind and water. Particles dispersed by water tend to fill the surrounding pores, restricting the movement of water and air into the soil profile. When this occurs at the soil surface, caps may form that can restrict seedling emergence, and impede drainage (Beare et al. 2005). Research has shown that soil with low aggregate stability also have lower crop yields (Beare et al. 2005). Because aggregates are mostly affected by cultivation practices, aggregate stability is only monitored at the market garden sites.

The organic resources are established from the soil’s total carbon, total nitrogen and mineralisable nitrogen. Carbon is one of the basic building blocks of organic matter which helps soils retain moisture and nutrients, and gives good soil structure for water movement and growth. The total content of organic matter in the soil is not easily measured accurately, but soil carbon can be measured accurately (SINDI 2010). Consequently, total carbon is measured and used as an estimate of the soil organic matter content of the soil. Soil organic matter and carbon levels are particularly susceptible when land is used for market gardening and cropping. Intensive cultivation can lead to a considerable reduction in soil organic matter and carbon through increasing the rate of organic matter decomposition in soil, reducing inputs of organic residues to the soil each year 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 and total nitrogen gives a measure of those reserves. In general, high total nitrogen indicates the soil is in good biological condition. However, very high total nitrogen contents increase the risk that nitrogen supply may be in excess of plant demand, and ultimately lead to leaching of nitrate to groundwater (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 the

[16] For the purposes of this report macroporosity is measured at a pressure of -10 kPa. It is also commonly known as and reported in the results in Appendix 3 as “air filled porosity”.

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 acts as a surrogate measure for microbial biomass (SINDI 2010).

Acidity is a measure of the soil's pH. Most plants and soil organisms have an optimum soil pH range for growth. Most New Zealand soils have a pH within the range of 3 to 9, but many unmodified New Zealand soils have a pH between 4 and 5, which needs to be raised to grow crops and productive pasture (SINDI 2010). Indigenous species are generally tolerant of acidic conditions but introduced pasture and crop species require a more alkaline soil (Hill & Sparling 2009). A common farming practice to raise soil pH and reduce the acidity of the soil is to add limestone ($CaCO_3$). The application of fertilisers containing ammonium or urea has the opposite effect, speeding up the rate at which acidity develops. Soil pH also influences the solubility and availability of a wide range of compounds in soil.

Fertility is determined by the Olsen P concentration of the soil. Olsen P is the plant available fraction of phosphates in the soil. Phosphorus (like nitrogen) is an essential nutrient for plants and animals. Many soils in New Zealand have low available phosphorus and phosphorus needs to be added for agricultural use, usually in the form of soluble fertiliser sources such as super-phosphate or di-ammonium phosphate (Kim & Taylor 2009). Phosphate is normally strongly bound to soils, but high levels on shallow soils with low P retention have a risk of phosphorus leaching and contaminating groundwater. Phosphorus is often bound to surface soil particles, and surface erosion causing sediment to reach waters often carries phosphate as well. Again, this may result in contamination of water and enhanced algal growth (SINDI 2010).

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 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 (Stevenson 2008), trace elements can become toxic at higher concentrations (Kim & Taylor 2009).

Appendix 4: Soil quality indicator target ranges

Soil quality indicator target (or optimal) ranges from Hill and Sparling (2009) are outlined in the tables below, along with guideline values for trace element concentrations in soil, adapted from NZWWA (2003).

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

Notes:
Applicable to all land uses
Target ranges for cropping and horticulture are poorly defined

Macroporosity target ranges (% @ -10 kPa)

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

Notes:
1: Revised base don Mackay et al. (2006)
Applicable to all Soil Orders
Target ranges for cropping and horticulture are poorly defined

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

Notes:
Applicable to all Soil Orders
Organic soils by definition must have >15% total C content, hence C content is not a quality indicator for that order and is defined as an "exclusion"
Target ranges for cropping and horticulture are poorly defined

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					

Notes:
Applicable to all Soil Orders
Target ranges for cropping and horticulture are not specified as target values will depend on the specific crop grown

Anaerobic mineralisable nitrogen (AMN) 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

Notes:
Applicable to all Soil Orders
Target ranges for cropping and horticulture are poorly defined

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					

Notes:
Applicable to all Soil Orders
Target ranges for cropping and horticulture are general averages and target values will depend on the specific crop grown
Exclusion is given for forestry on organic soils as this combination is unlikely because of wind throw

Olsen P target ranges (mg/kg)

	Very low	Low	Adequate	Ample	High	
Pasture on Sedimentary and Allophanic soils	0	15	20	50	100	200
Pasture on Pumice and Organic soils	0	15	35	60	100	200
Cropping and horticulture on Sedimentary and Allophanic soils	0	20	50	100	100	200
Cropping and horticulture on Pumice and Organic soils	0	25	60	100	100	200
Forestry on all Soil Orders	0	5	10	100	100	200

Notes:
Sedimentary soil includes all other Soil Orders except Allophanic (volcanic ash), Pumice, Organic and Recent (AgResearch classification system)

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

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