

Environment Committee Meeting

1 September 2022

This Report relates to Item 9 in the Agenda

“Soil Quality Monitoring Review”

Soil quality monitoring programme review for Marlborough district.



Report prepared by:

Reece Hill (Landsystems) and Alistair Dunn (Ocean Environmental)

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For:

Matt Oliver - Marlborough District Council

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Executive summary

Regional authorities have a responsibility for promoting the sustainable management of the natural and physical resources of their region. Under Section 35 of the Resource Management Act (1991) there is a duty to monitor and report on the soil resource. The collection of detailed soil monitoring data is vital because it provides information on the effects of current land use activities on soil quality and whether there is a need to change soil and land management policy and activities. This is becoming increasingly important as land use activities intensify, putting pressure on the finite soil resource.

Project and Client

Marlborough District Council engaged Landsystems to provide a review of their soil quality and trace element monitoring programme for the Marlborough District.

Marlborough District Council is one of 15 councils nationally, monitoring soil quality in their region. Soil quality and trace element monitoring provides useful information for managing soils locally as well as contributing soil quality data for national reporting.

Objectives

- Provide an analysis of the existing soil quality and trace element monitoring programme including:
 - a summary of the current monitoring programme,
 - the minimum number of sites required for each land use / soil order combination, and the level of change and timeframe for detection,
 - the number of additional sites of each land use /soil order combination that may be required,
 - guidance on the frequency of sampling,
 - recommendations as to the most appropriate location of new sites,
 - statistically based recommendations on what to do with excess sites,
 - recommendations for removing or retaining sites, and
 - improvements for the programme going forward.

Assessment of programme

- Sample data from a total of 96 sites (both current and inactive sites) was available for analysis. The total number of individual samples through the period 2000 to 2020 was 386, although not all analyses were undertaken at each sampling.
- Landcover Database data for 2001 and 2018 and New Zealand Fundamental Soil Layer data were used to estimate the area of land in the different land uses represented in the soil quality monitoring programme and the area of each soil order represented within each land use.
- An assessment of the current monitoring sites included a power analysis to determine the number of sites required to identify changes in values for each soil quality and

trace element indicators between samplings. Coefficient of variance for each soil quality indicator were estimated from the existing data set, and sample size requirements, using the most applicable coefficient of variance, were estimated for a range of potential changes in soil quality indicators with a confidence of 80%.

Main points

- The MDC soil quality monitoring programme is well established with 386 samples collected from 96 sites since 2000.
- The monitoring programme follows nationally agreed methods.
- A power analysis used to assessment sample size requirements for the monitoring programme indicated that 30 to 40 sites per land use would for all but the Olsen P indicator, be optimal to have an 80% probability of detecting a reduction in cases where there was a true 50% change (i.e. a 50% reduction or increase).
- In addition to the power analysis, other factors were taken into consideration when determining the number of samples in the soil quality monitoring programme, including resource availability, costs, and practical sampling limitations.
- With other considerations, a monitoring programme with 123 sites seemed practical, and will likely provide a monitoring programme with an adequate minimum number of sites and data for assessing long term trends with an ability to detect a change of at least 50%.
- A monitoring programme of 123 sites was recommended, consisting of 25 sites for intensive land use types, 20 sites for less intensive land use types, and eight sites for 'reference' indigenous sites.
- An assessment of the weighting of sites by soil order area within a land use type indicated that the distribution of sites did not fully represent the soil orders likely to be present.
- Under-represented soils included Gley and Recent soils for cropping sites, Brown, Pallic and Ultic soils for exotic forest sites, and Recent soils for viticulture sites.
- Over-represented soils included Pallic soils on viticulture sites.
- Based on the power analysis, there are no excess sites in the current monitoring programme and any new sites added to the programme should be in addition to the current sites.
- The number of sites in the current monitoring programme (91 sites) is low compared with other regional monitoring programmes. Increasing the number of sites to 123 sites would increase the density of sites to 101 km²/site, in line with other regions.

Conclusions

- The MDC soil quality monitoring programme is soundly based, following nationally agreed methods.
- The number of current sites is low compared with other regional monitoring programmes.
- Based on the current number of sites, the MDC soil quality monitoring programme is

unlikely to provide adequate precision to detect large changes in the long-term trends for most soil quality indicators.

- Increasing the number of sites for land use types (excluding indigenous vegetation) to a minimum of 20 to 25 sites per land use type would improve the precision of detection for assessing long term changes in soil quality. If greater precision were required, then the number of sites per land use type would need to be increased.
- Increasing the number of sites for indigenous vegetation to eight sites would provide 'reference' sites for the main soil orders across all land use types.
- The number of sites in the current monitoring programme (91 sites) is low compared with other regional monitoring programmes. Increasing the number of sites to 123 sites would increase the density of sites to 101 km²/site, in line with other regions.

Recommendations

- Continue to monitor soil quality in the Marlborough district, resampling between 20-30 sites annually to maintain sufficient data for assessing long term soil quality trends in the region.
- Increase the minimum number of sites in the monitoring programme to an adequate minimum of 20-25 per land use (excluding indigenous vegetation) depending on the intensity of land use types.
- Increase the number of sites for indigenous vegetation to eight sites to provide 'reference' sites for the main soil orders across all land use types.
- Additional sites should be prioritised towards the underrepresented soil orders for each land use to improve the representation of the main soil orders within each land use type.

Acknowledgements

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Introduction

The Resource Management Act (1991) Section 35 requires regional authorities (regional councils and unitary authorities) to report on the “life supporting capacity of soil” and whether current practices will meet the “foreseeable needs of future generations”. Many councils have established regional soil quality monitoring programmes that follow the protocols established in a 6-year trial, commonly known as the “500 Soils Project”, and subsequently revised for regional monitoring (Hill et al., 2003; Hill and Sparling 2009).

Currently 15 regional authorities monitor soil quality and a subset of these include soil trace element monitoring. Regional soil quality monitoring data has been compiled from participating regions for national soil quality reporting - Our Land 2018 (MfE, 2018).

The Marlborough District Council (MDC) soil quality and trace element monitoring programme informs regional State of Environment (SoE) reporting and contributes to national reporting.

Soil quality and trace element monitoring data provides information on the effects of current management practices (for a given land use) on the soil and whether soil management needs to be changed to better manage the land environment. Also, the way soils respond to different land use activities can affect the surrounding environment. For example, reduced soil quality can lead to reduced infiltration and increased surface runoff of soil and contaminants into surface waterways. Knowing the state of our soil quality and how it is changing is becoming increasingly important as land use activities are intensifying across New Zealand.

Aim

The aim of this report is to provide an assessment of the current soil quality monitoring programme for the Marlborough district.

Objectives

The main objective of the review is to provide an analysis of the existing soil quality monitoring programme including:

- a summary of the current monitoring programme,
- the number of additional sites of each land use/soil order combination that may be required,
- the minimum number of sites required for each land use / soil order combination, and the level of change and timeframe for detection,
- guidance on the frequency of sampling,
- recommendations as to the most appropriate location of new sites,
- statistically based recommendations on what to do with excess sites,
- recommendations for removing or retaining sites, and
- improvements for the programme going forward.

Approach

To address the review objectives, the following general steps provided an approach for the review:

1. identify the current number of sites and available dataset,
2. identify the current distribution of sites across land uses and soils in the region,
3. estimate the proportions of land use and soils in the region,
4. statistically estimate the minimum number of sites required for each land use to detect soil quality changes over time,
5. assess the distribution of current sites against estimates of required sites and their distribution,
6. consider other regional soil quality monitoring programmes, and
7. consider resource availability and other practical limitations.

Soil monitoring programme background

Preliminary work to develop soil quality monitoring nationally was initiated across several regions in 1995 (Hill and Sparling, 2009). As part of the Marlborough District's contribution to this initiative, an initial set of 25 soil quality sites were established. The national initiative provided the basis for the regional soil quality monitoring programme for the Marlborough District which has since been incrementally developed since 2000. Annual sampling and resampling of established sites has continued, although annual sampling was not undertaken in all years. Soil quality monitoring sites cover the range of land uses and soils in the region, with sampling frequency varying across land uses, depending on the intensity of the land use. On average the programme is set up to provide resampling of sites at five yearly intervals with annual reporting.

Soil quality is assessed based on a nationally agreed suite of seven key soil chemical, physical and biological indicators and eight trace elements.

Land use in the Marlborough District has changed over the past two decades which has impacted on soil monitoring site representativity. The main changes in land use since 2000 have been conversion of pasture to viticulture.

Land use change at individual monitoring sites changes the sample size for a land use, meaning the site is no longer useful for resampling to assess soil quality changes over time for the original land use. This provides challenges for maintaining a representative monitoring programme through time.

Alignment with national monitoring guidelines and standards

The most commonly used guidelines used by councils for SOE soil quality and trace element monitoring are provided by Hill and Sparling (2009) for soil quality and by Taylor and Kim (2009) for trace elements.

Regional soil quality and trace element monitoring in the Marlborough District has followed these guidelines. However, of the guideline components, the collection of site management data is absent or minimal and could be improved. The improved site management information would assist with the interpretation of sample data for reporting.

National Environmental Monitoring Standards for soil quality and trace elements (NEMS, 2022) have recently been released. The NEMS is largely based on Hill and Sparling (2009) for soil quality and Taylor and Kim (2009) for trace elements, with some updates. There are no major changes likely to impact on to methods currently used for the MDC monitoring programme, however, future monitoring should include any updates provided in the National Environmental Monitoring Standards for soil quality and trace elements.

Current programme overview

The MDC soil quality monitoring programme has been monitoring soil quality and trace elements since 2000. The current MDC soil quality monitoring programme consists of 91 active sites. The distribution of sites across the region is shown in **Figure 1**.

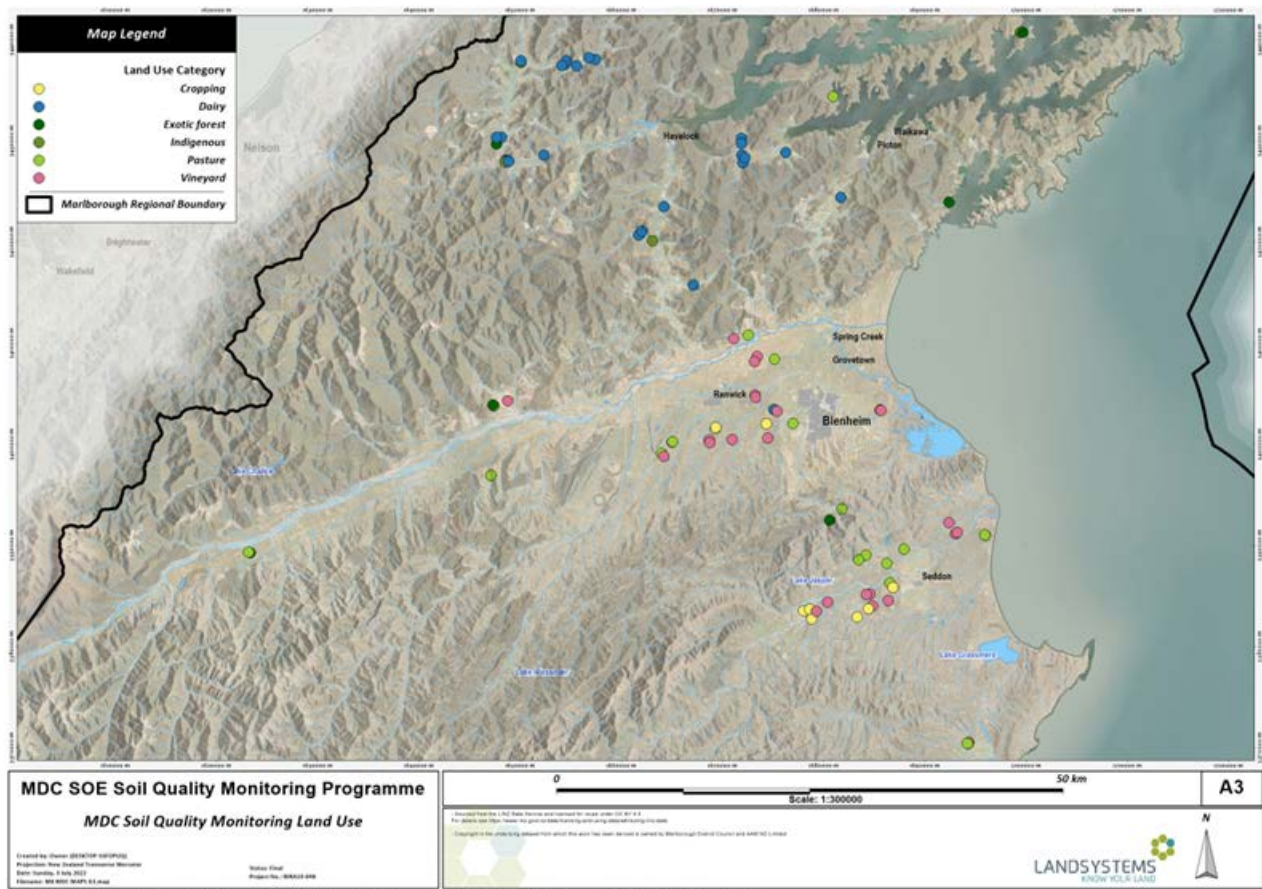


Figure 1. Distribution of soil quality monitoring sites (as of 2020) in the Marlborough region.

Historically the number of sites has included up to 96 sites (Cavanagh et al. 2017) with five sites being discontinued, primarily due to land use changes. The distribution of the current sites by land use type and soil order is shown in **Table 1**.

Table 1. The distribution of the available sites across land use and soil order.

Site distribution by land use and soil order					
MDC land use	Soil order				
	Brown	Gley	Pallic	Recent	Total
Number of sites (n)					
Cropping	1	0	9	2	12
Dairy	11	0	0	15	26
Exotic forest	5	0	2	0	7
Indigenous vegetation	2	0	0	2	4
Pasture	5	0	11	1	17
Vineyard	3	3	14	5	25
Total	27	3	36	25	91
Percentage of sites (%)					
Cropping	1%	0%	10%	2%	13%
Dairy	12%	0%	0%	16%	29%
Exotic forest	5%	0%	2%	0%	8%
Indigenous vegetation	2%	0%	0%	2%	4%
Pasture	5%	0%	12%	1%	19%
Vineyard	3%	3%	15%	5%	27%
Total	30%	3%	40%	27%	100%

The MDC soil quality monitoring programme includes the nationally agreed suite of seven key soil chemical, physical and biological indicators and eight trace elements. The dataset to date includes 386 site samplings, with 5283 individual data points across all 15 parameters. Not all of the seven soil quality indicators¹ and eight soil trace elements were analysed for every sampling. This is a common occurrence for many councils and is largely due to incremental changes to national soil quality monitoring methods over the past 20 years. The number of data points in the available dataset is shown in **Table 2**.

¹ Soil quality indicators include: soil pH, total carbon, total nitrogen, Olsen phosphorus, anaerobic mineralisable nitrogen, bulk density and; soil trace elements include: arsenic, cadmium, chromium, copper, fluoride, lead, nickel and zinc.

Table 2. Number of data points for soil quality indicators and trace elements in the MDC soil quality monitoring programme (2000 to 2020).

	Parameter	Number of samples
Soil quality indicators	Soil pH	386
	Total carbon	386
	Total nitrogen	386
	Olsen phosphorus	386
	Anaerobic mineralisable nitrogen	386
	Bulk density	385
	Air-filled porosity at -10 kPa	360
Soil trace elements	Arsenic	361
	Cadmium	361
	Chromium	361
	Copper	361
	Fluoride	81
	Lead	361
	Nickel	361
	Zinc	361

Assessment of programme

Land use in the Marlborough district

The relative proportions of different land use types in the Marlborough district and changes over time can be estimated using the New Zealand Land Cover Database (LCDB v5.0 - Land Cover Database version 5.0, Mainland, New Zealand)². Land use type changes for the period 2001 to 2018 which provides the closest data range to the length of the soil quality monitoring programme (2000 to 2020) are provided in **Table 3**.

² <https://iris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/>

Table 3. Estimated Land use type changes in the Marlborough district for the period 2001 to 2018.

LCDDB Land cover	Land area (ha)	% of region land area
2001		
Cropping	5008	0.5%
Exotic forest	77317	7.4%
Horticulture	12967	1.2%
Indigenous vegetation	529084	50.7%
Pasture	326833	31.3%
Total	951209	91.1%
2018		
Cropping	4091	0.4%
Exotic forest	88295	8.5%
Horticulture	30621	2.9%
Indigenous vegetation	527026	50.5%
Pasture	301820	28.9%
Total	951853	91.2%
2001-2018 change		% change of individual land cover
Cropping	-917	-18%
Exotic forest	10979	14%
Horticulture	17654	136%
Indigenous vegetation	-2058	0%
Pasture	-25013	-8%

The predominant land use types for 2018 by land area include (in decreasing order) indigenous vegetation (50.5%), pasture (28.9%), exotic forest (8.5%), horticulture (2.9%), and cropping (0.4%). No LCDDB data is available for dairy land use as this is included in the LCDDB land covers contributing to the pasture land use type. However, StatsNZ data³ indicates that the land area in dairy for the Marlborough region was 8199 ha in 2002, increasing to 10,057 ha in 2019. These areas of dairy equate to 2.5% of pasture land in 2001, and 3.3% of pasture land in 2018. The main changes in land use type from 2001 to 2018 were an increase in the area of horticulture (136%) and exotic forest (14%), and a decrease in cropping (18%).

Land use and soil order

The distribution of the current MDC soil quality monitoring sites by land use type and soil order is shown in **Table 4**.

³ <https://www.stats.govt.nz/indicators/agricultural-and-horticultural-land-use>

Table 4. The proportion of current MDC soil quality monitoring sites by land use type and soil order.

Soil order ⁴	Land use type				
	Cropping	Exotic forest	Horticulture (Vineyard)	Indigenous vegetation	Pasture (includes dairy)
Brown	8%	71%	12%	50%	37%
Gley	0%	0%	12%	0%	0%
Melanic	0%	0%	0%	0%	0%
Organic	0%	0%	0%	0%	0%
Pallic	75%	29%	56%	0%	26%
Podzol	0%	0%	0%	0%	0%
Raw	0%	0%	0%	0%	0%
Recent	17%	0%	20%	50%	37%
Ultic	0%	0%	0%	0%	0%
Total	100%	100%	100%	100%	100%

The proportions of each soil (soil order) for individual land use types in the region was estimated using LCDB data⁵ and NZFSL derived soil order data⁶ (**Table 5**). For comparison, the distribution of current sites is also provided in brackets.

Table 5. The proportion of each soil order for individual land use types in the Marlborough district estimated using the LCDB and NZFSL derived soil order data (proportion of current sites in brackets).

Soil order ⁷	Land use type				
	Cropping	Exotic forest	Horticulture	Indigenous vegetation	Pasture
Brown	2.4% (8%)	68.0% (71%)	13.0% (12%)	65.9% (50%)	34.7% (37%)
Gley	31.4%	0.1%	13.2% (12%)	0.0%	1.2%
Melanic	0.2%	0.1%	1.4%	0.8%	3.6%
Organic	0.3%	0.0%	0.1%	0.0%	0.0%
Pallic	36.2% (75%)	18.0% (29%)	26.5% (56%)	7.6%	49.6% (26%)
Podzol	0.0%	0.0%	0.0%	8.1%	0.7%
Raw	0.0%	0.3%	0.0%	4.3%	1.0%
Recent	29.5% (17%)	1.7%	45.9% (20%)	0.5% (50%)	6.4% (37%)
Ultic	0.0%	11.8%	0.0%	12.8%	2.8%

Based on the estimates, cropping land use is predominantly on Pallic, Gley and Recent soils, exotic forest on Brown, Pallic and Ultic soils, horticulture on Recent, Pallic, Brown and Gley soils, indigenous vegetation on Brown, Ultic, Podzol and Pallic soils, with pasture on Pallic, Brown and Recent soils.

The proportion of soil orders on an individual land use type provides guidance for weighting

⁴ Hewitt, A.E. (2010). New Zealand Soil Classification. Landcare Research Science Series No.1, 3rd edition, Manaaki Whenua Press, Lincoln, New Zealand.

⁵ <https://iris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/>

⁶ <https://iris.scinfo.org.nz/layer/48079-fsl-new-zealand-soil-classification/>

⁷ Hewitt, A.E. (2010). New Zealand Soil Classification. Landcare Research Science Series No.1, 3rd edition, Manaaki Whenua Press, Lincoln, New Zealand.

the number of soil quality sites to ensure the dominant soil orders for each land use type are proportionately represented.

Minimum number of sites by land use

The number of sites that would be required to determine a statistically significant difference in soil quality indicators can be estimated using a power analysis. The power analysis provides statistically based guidance on the minimum sample size that would be required to detect an effect of a given size with a given level of confidence.

The power analysis was used to determine the number of soil quality sites required to detect the changes in values of each soil quality indicator between an initial sampling and subsequent resampling.

Coefficient of variance (cv) is unitless measure that provides a relative measure of variability that indicates the size of the standard deviation of a set of values in relation to their mean. It provides a comparative measure of the variability between disparate groups and characteristics.

The coefficients of variance for soil quality indicators and trace elements were estimated from the existing MDC soil quality monitoring dataset, and sample number requirements for the most applicable coefficient of variance used to estimate required sample sizes for a range of changes in the values (as a percentage) with a confidence of 80%.

The coefficient of variability for soil quality indicators and soil trace elements are shown in **Figure 2** and **Figure 3** respectively.

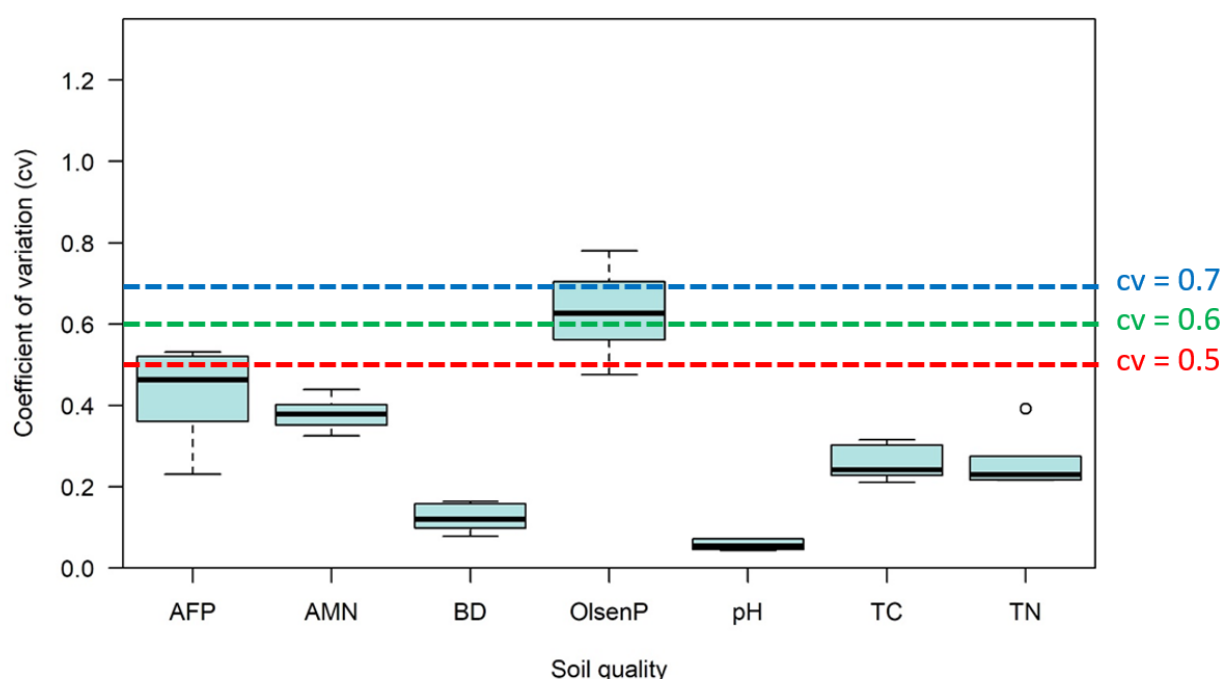


Figure 2. Coefficient of variance for soil quality indicators.

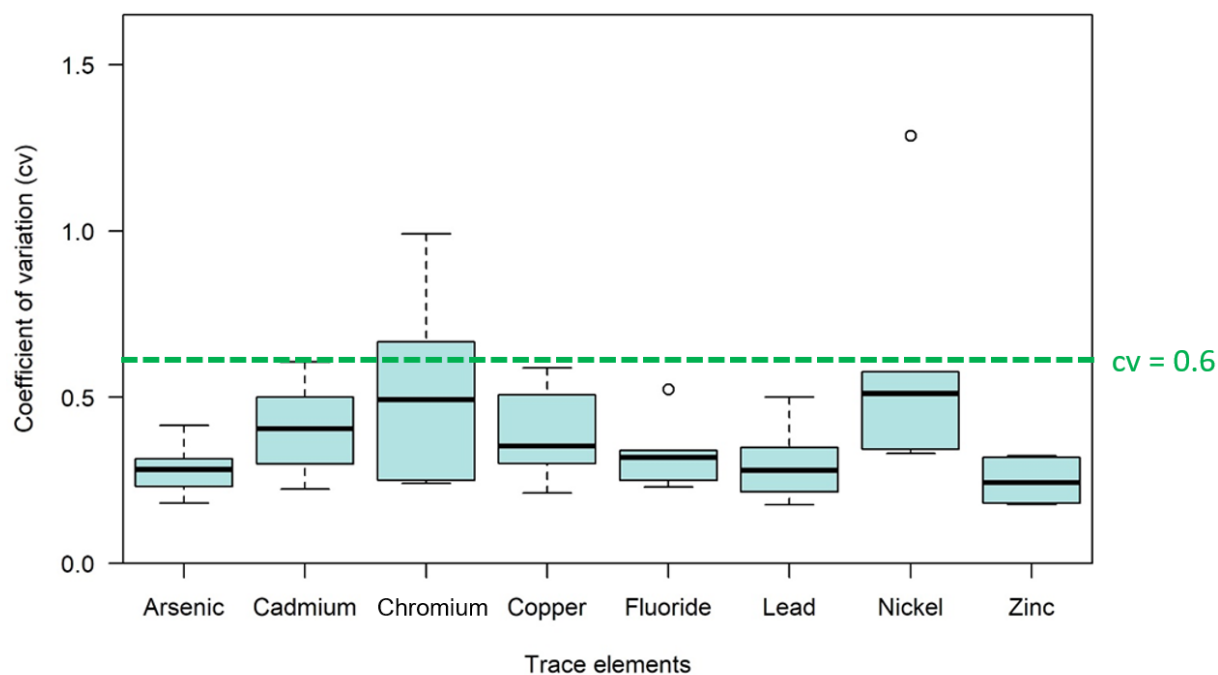


Figure 3. Coefficient of variance for soil trace elements.

For soil quality indicators, mean cv values were all below 0.6, with the exception of Olsen P, which had a cv between 0.6 and 0.7. For Olsen P the greater variability (as represented by the higher cv) is likely to be the result of varying fertiliser applications on the different sites across land use types. For example, more intensive land uses such as cropping and dairy will apply more phosphate fertiliser than exotic forest and pasture sites. The implications of this are that more samples are likely to be required to detect trends, compared with the other soil quality indicators. For trace elements, mean cv values were all below 0.6.

A power analysis for two groups with a cv = 0.5, cv = 0.6, and cv = 0.7 were calculated (**Figure 4**, **Figure 5** and **Figure 6**). The power analysis shows that as the cv for an indicator increases, a larger sample is required to achieve a target power.

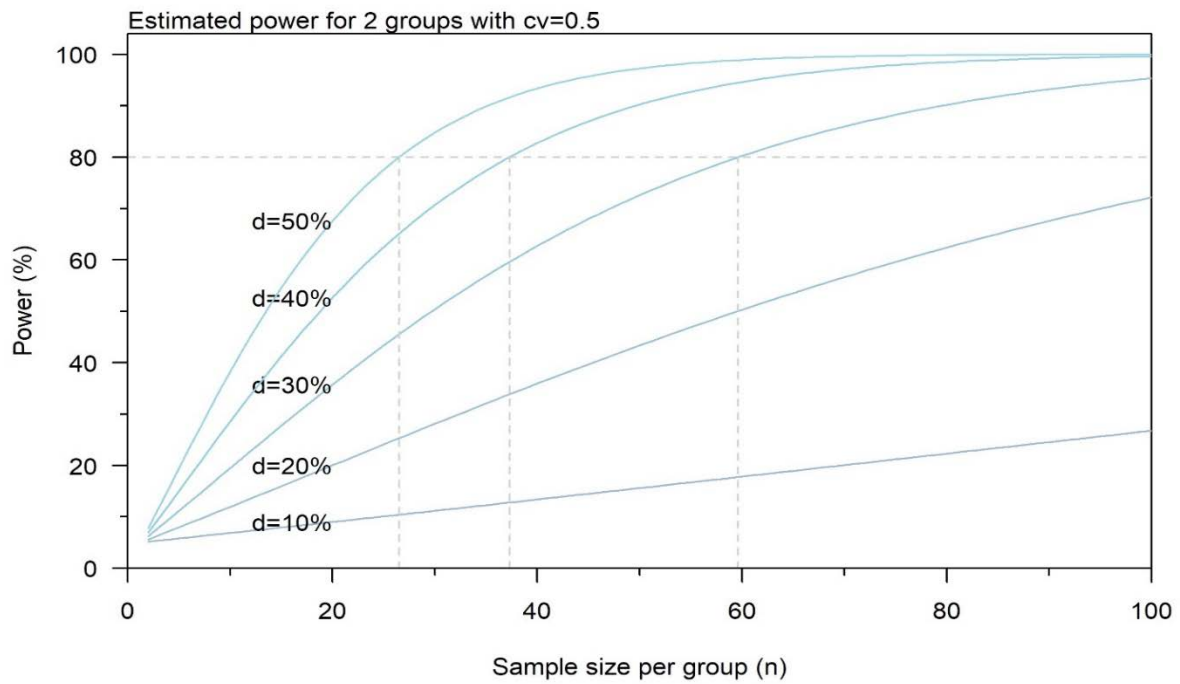


Figure 4. Estimated power for two (2) groups with $cv = 0.5$ for soil quality indicators.

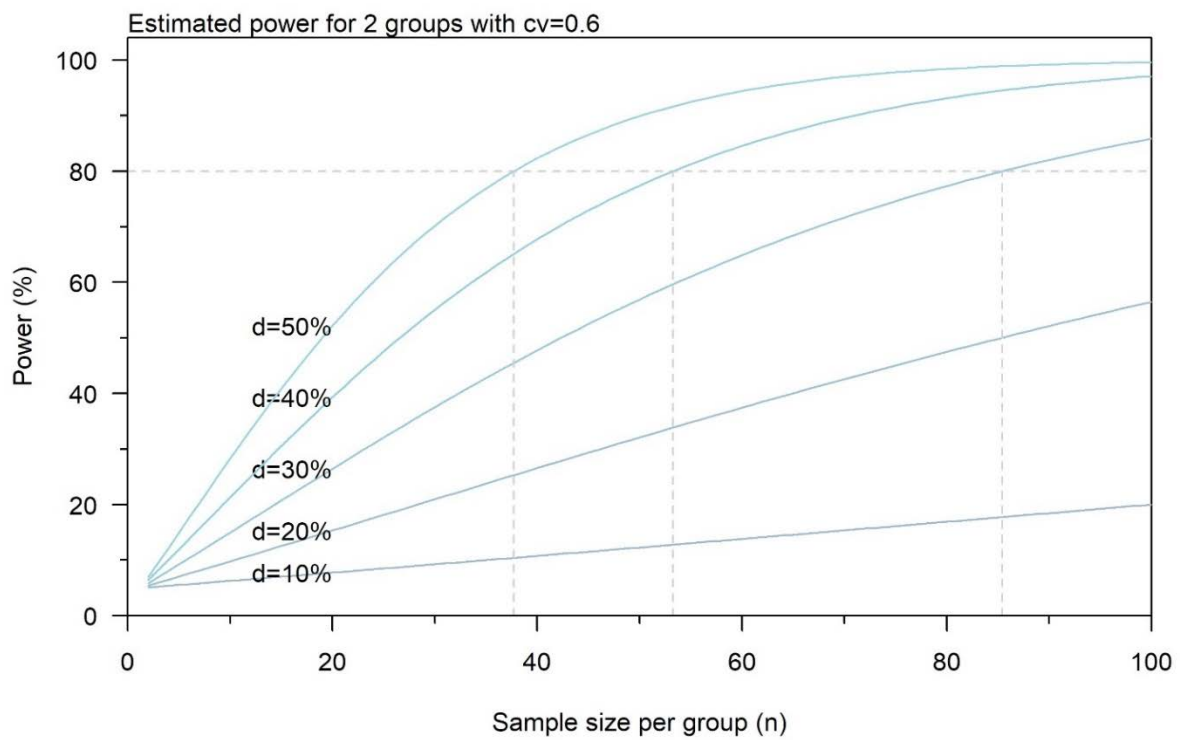


Figure 5. Estimated power for two (2) groups with $cv = 0.6$ for soil quality indicators.

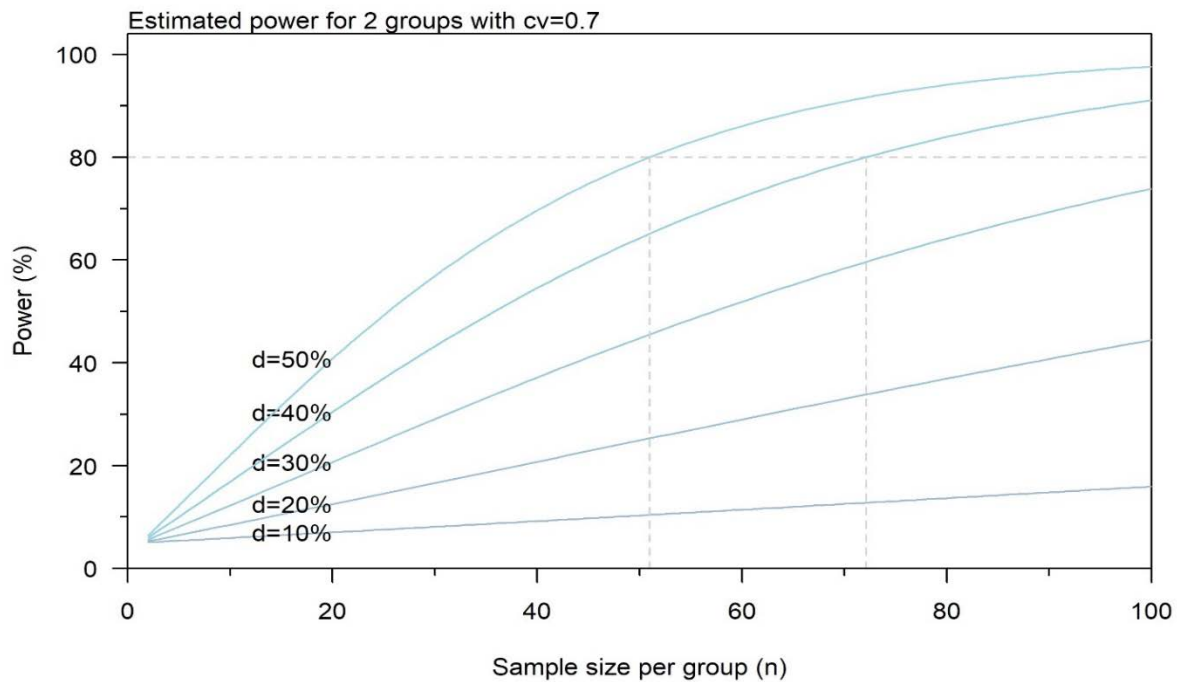


Figure 6. Estimated power for two (2) groups with $cv = 0.7$ for soil quality indicators.

The difference (d) is the percentage change that can be detected with a given confidence (power). The smaller the difference that is required to be detected, the greater the number of samples required to detect the change for a given power. For a sampling interval of five years, a difference of $d = 50\%$ would equate to detecting an average annual change of 10% , equivalent to a 50% over the five year period. The value of difference selected is somewhat subjective but should be based on the likely changes anticipated between samplings.

Based on the power analyses and with $d = 50\%$ and a confidence of 80% , the number of required samples was 20 to 30 for a $cv = 0.5$, 30 to 40 for $cv = 0.6$, and 50 to 60 samples for $cv = 0.7$.

As an additional test of the most acceptable difference (d), the observed annual changes in the soil quality indicators from 2000 to 2020 were calculated. The annual changes were then multiplied by five to approximate the total percentage difference that could be expected between two sampling events over a five year interval (**Figure 7**).

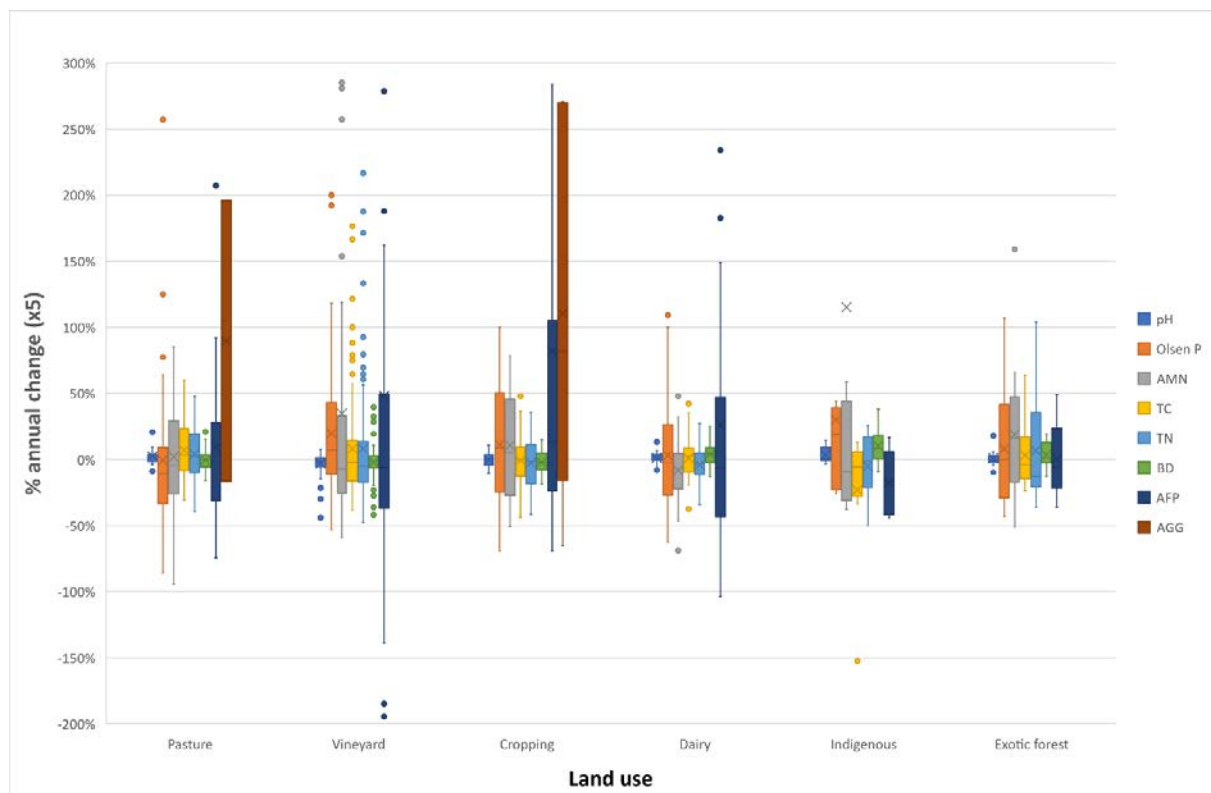


Figure 7. Percentage annual changes for soil quality indicator data (x5).

This analysis indicated that the majority of the percentage changes between two samplings with a five-year interval would likely lie within a $\pm 50\%$ range, and that $d = 50\%$. However, the timeframe for this detection is also important to consider. The annual changes shown in **Figure 7**. Indicate the short term (annual) variability in the data, whereas for the soil quality monitoring programme is focused on identifying long term trends in soil quality indicators and trace elements, which are likely to be much less than $\pm 50\%$ between samplings over the longer term. Furthermore, for less intensive land uses such as exotic forest and pasture, changes are likely to occur over a longer time frame (greater than a five-year interval) and a smaller sample size is acceptable.

Based on the analysis, applying the commonly used power of 80%, with the estimated $cv = 0.6$, a minimum of 30 sites per land use type is the likely optimal for detecting the changes expected (i.e. $d = 50\%$) between samplings with an interval of five years (as is commonly used for the MDC soil quality monitoring programme). However, a lesser number of sites of 25 sites for intensive land use types (cropping, dairy and horticulture), and 20 sites for less intensive land use types (exotic forest and pasture) is likely to provide an adequate minimum.

Indigenous vegetation sites are excluded because they essentially serve the purpose of providing a reference against which to compare 'farmed sites' (cropping, dairy, exotic forest and horticulture). For this reason, a minimum set of indigenous sites are best selected to cover the range of soil orders that occur on the farmed sites. For the Marlborough region, farmed sites occur mostly on Brown, Pallic and Recent soils, and to a lesser extent on Gley and Ultic soils. Currently indigenous vegetation sites are represented on Brown soils (two sites) and Recent soils (two sites). Increasing the number of indigenous vegetation sites to eight to ten sites, including two additional sites on Pallic soils, and at least one site each on Gley and

Ultic soils would provide acceptable coverage.

A suggested acceptable minimum number of sites for land use types with an average sampling interval of five years is shown in **Table 6**.

Table 6. Suggested acceptable minimum number of sites for land use types with an average sampling interval of five years for the MDC soil quality monitoring programme.

Land use type	Number of sites	Current number of sites	Additional sites suggested
Cropping	25	12	13
Dairy	25	26	0
Exotic forest	20	7	13
Indigenous vegetation	8	4	4
Pasture	20	17	3
Vineyard	25	25	0
Total	123	91	33

For dairy and vineyard, the current number of sites is likely to provide an adequate minimum. For cropping, exotic forest indigenous vegetation and pasture additional sites are required to provide an adequate minimum.

Weighting of sites by soil order

Hill et al. (2003) recommended reporting by land use type, weighting the sites within a land use type according to the most common soils (soil order). The area proportions of the different land use types (based on the LCDB data) and soil order can be used to weight the number of sites for each land use type by soil to ensure the main soils for each land use type are represented (**Table 7**).

Table 7. Area proportions of the different land use types and soil order (based on LCDB and NZFSL data).

Soil order ⁸	Land use type				
	Cropping	Exotic forest	Horticulture	Indigenous vegetation	Pasture
Brown	2.4%	68.0%	13.0%	65.9%	34.7%
Gley	31.4%	0.1%	13.2%	0.0%	1.2%
Melanic	0.2%	0.1%	1.4%	0.8%	3.6%
Organic	0.3%	0.0%	0.1%	0.0%	0.0%
Pallic	36.2%	18.0%	26.5%	7.6%	49.6%
Podzol	0.0%	0.0%	0.0%	8.1%	0.7%
Raw	0.0%	0.3%	0.0%	4.3%	1.0%
Recent	29.5%	1.7%	45.9%	0.5%	6.4%
Ultic	0.0%	11.8%	0.0%	12.8%	2.8%
Total	100%	100%	100%	100%	100%

⁸ Hewitt, A.E. (2010). New Zealand Soil Classification. Landcare Research Science Series No.1, 3rd edition, Manaaki Whenua Press, Lincoln, New Zealand.

Using the adequate minimum number of 123 sites provided in **Table 6**, the proportions provided in **Table 7** can be used to identify how many sites are required on each soil order within a land use type to ensure the main soils for each land use type are represented.

Table 8 compares the estimated distribution of sites and the current distribution of sites by land use type and soil order. The text in red indicates where the required additional sites could be added to provide a more representative programme based on soil order weighting.

Table 8. The current and estimated distribution of sites by land use type and soil order (text in red indicates where additional sites could be added).

Land use type	Soil order weighting by land use type (decreasing left to right); first number = current sites, second number = monitoring programme with 123 sites.							
Cropping	Pallic (9) (9)	Gley (0) (8)	Recent (2) (7)	Brown (1) (1)	Organic (0) (0)	Melanic (0) (0)		
Dairy*	Recent (15)	Brown (11)						
Exotic forest	Brown (5) (14)	Pallic (2) (4)	Ultic (0) (2)	Recent (0) (0)	Raw (0) (0)	Gley (0) (0)	Melanic (0) (0)	
Horticulture (Vineyard)	Recent (5) (12)	Pallic (14) (7)	Gley (3) (3)	Brown (3) (3)	Melanic (0) (0)	Organic (0) (0)		
Indigenous vegetation**	Brown (2) (2)	Ultic (0) (1)	Podzol (0) (0)	Pallic (0) (2)	Raw (0) (0)	Melanic (0) (0)	Recent (2) (2)	Gley (0) (1)
Pasture	Pallic (11) (10)	Brown (5) (7)	Recent (1) (1)	Melanic (0) (1)	Ultic (0) (1)	Gley (0) (0)	Raw (0) (0)	Podzol (0) (0)

* No LCDB data for dairy; ** sites allocated to cover main soil orders represented across all land use types.

The location of additional sites can be approximated spatially by intersecting LDCB (or other available spatial land use layer) with available soil map information such as the NZFSL or S-map data using a geographic information system (GIS). It is important to note that this is only likely to provide a regional scale guide for the identification of new sites. Field confirmation of both land use type and soil order are essential and are a requirement of the (to be released) National Environmental Monitoring Standards for soil quality and trace elements.

Sampling frequency

The number of site samples collected annually from 2000 to 2020 is shown in **Figure 8**.

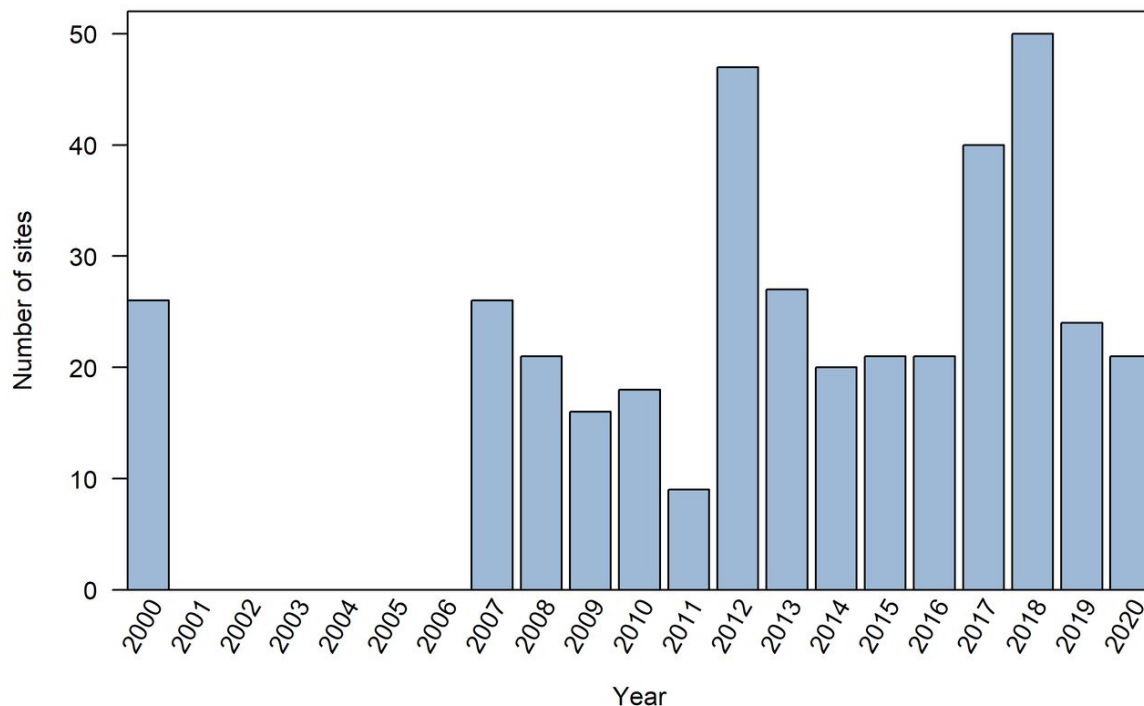


Figure 8. Number of MDC soil quality monitoring sites sampled annually from 2000 to 2018.

On average between 20 to 30 sites have been sampled annually with up to 50 sites sampled and as low as 10 sites sampled in a given year. These variations in number of sites sampled are mostly due to the number of vineyard sites included in a given year. Vineyard sites each have three 'subsites', vine, inter-row and wheel track. Smaller variations in the number sites sampled in a given year is likely due to the loss of sites, adding sites for land uses with a low number of sites or because of resource availability.

In general, between 20 and 30 sites seems to be logistically feasible. This provides some guidance when developing a robust and achievable soil quality monitoring programme into the future.

The sampling frequency of sites sampled more than once for different land uses is shown in **Table 9**.

Table 9. The sampling frequency for different land uses used in the Marlborough district soil quality monitoring programme.

Land use type	MDC land use	Sampling frequency (years)	Count (n)
Cropping	Cropping	5	21
		6	1
		7	6
Dairy	Dairy	4	11
		5	17
		7	4
		9	2
Exotic forest	Exotic forest	3	1
		4	2
		5	6
		7	2
		9	1
		10	2
Indigenous vegetation	Indigenous vegetation	1	1
		5	1
		7	3
		9	2
		10	1
Drystock	Pasture	3	1
		4	1
		5	33
		6	1
		7	8
Horticulture	Vineyard	1	6
		4	3
		5	28
		6	5
		7	2

With the exception of indigenous vegetation, sites for all land uses are resampled most commonly every five years. Six vineyard sites have been sampled at a one year interval. These sites have recently been added and were part of a paired site study of land use change from pasture to vineyard. The indigenous vegetation sites have been sampled less frequently (commonly at 10 yearly intervals) because the soil quality is less likely to change over the shorter term. The variable sampling frequency is most likely due to the addition of new sites and logistical reasons, such as access to a site or resource constraints in a given year.

Although five yearly resampling should be aimed for, some resampling frequency variability is acceptable. Increasing or decreasing the resampling frequency will impact on the time to obtain a sufficient dataset that can identify statistically significant trends (i.e. sites sampled less frequently provide sparse data for statistically assessing trends).

In general, sampling has annually focused on rotating through the sites on a five year resampling frequency. This seems to provide the best logistical approach and is line with guidance provided for national soil quality monitoring (NEMS, 2022; Hill and Sparling, 2009).

Comparison with other regional programmes

A comparison with other regional monitoring programmes was used to provide a comparison of site density for the Marlborough district programme based on the current 91 sites, and 123 site and 160 site⁹ options (**Table 10**).

Table 10. Example number of sites and their distribution across land uses for soil quality monitoring programmes compared with Marlborough (adapted from Cavanagh et al., 2017).

Region	Area (km ²)*	Number of sites*	Regional density of sites (sites/km ²)	Regional density of sites (km ² /site)
Auckland	4894	124	0.025	39
Waikato	25,000	156	0.006	160
Hawke's Bay	14,111	86	0.006	164
Greater Wellington	8130	118	0.015	69
Bay of Plenty	12,282	72	0.006	171
Average	12,883	111	0.012	121
Marlborough (current)	12,484	91	0.007	137
Marlborough (123 sites)	12,484	123	0.010	101
Marlborough (160 sites)	12,484	160	0.012	78

* Regional areas and number of sites from Cavanagh et al. (2017).

With the exception of the Auckland region (which is smaller in size and has greater site density) site densities for the other regions range between 69 and 164 km²/site. This suggests that a monitoring programme of 123 sites or 160 sites are adequate, providing a site density of 101 km²/site and 78 km²/site respectively, and comparing well with monitoring programmes in other regions.

PCE 2019 report assessment of soil quality site density

A report by the Parliamentary Commissioner for the Environment (PCE) *Focusing Aotearoa New Zealand's environmental reporting system* (PCE, 2019), assessed the density of soil quality monitoring sites across regions in New Zealand.

Based on their assessment, the density of sites (96 sites across a land area of 10,458 ha) for the Marlborough region was considered moderate compared to other regions. The current soil quality monitoring programme has slightly less sites (91 sites) and would be considered moderate compared to other regions.

Of all the regions, only Nelson City, Greater Wellington and Auckland regions were considered high compared to other regions.

Based on the land area used by the PCE for the Marlborough region (10,458 ha), increasing the soil quality monitoring programme to 123 sites would increase the density of sites to one site per 85 km², which would be considered high compared to other regions.

⁹ Based on the acceptable minimum number of sites identified by the power analysis; 10 indigenous sites and 30 sites for all other land use types.

Excess sites

Based on the power analysis, the optimum number of sites is between 30 and 40 sites for the land use types, and the adequate minimum number of sites is between 20 and 25 (excluding indigenous vegetation and depending on land use intensity). All land use types in the current monitoring programme have less than 30 sites, and with the exceptions of dairy (26 current sites) and vineyard (25 sites) are below an adequate minimum number. For dairy, the single additional site above the adequate minimum should be retained as the data for this site provides valuable data for trend analysis on this intensive land use type. Therefore, there are currently no excess sites in the current monitoring programme.

Historically the land use for some sites has changed and this occurrence is most likely to continue to occur for future monitoring. However, given the optimum number of sites is between 30 and 40, and considering the resource limitation of the monitoring programme, it is unlikely that a situation will occur where there are excess sites.

If in the future, excess sites do occur, possibly as the dataset grows and a subsequent reanalysis of the dataset shows a requirement for a lower minimum number of sites, then removal (and redeployment of resources) to balance the distribution of sites across land use types should be considered.

Removal of sites

All historic sites and data are valuable for assessing trends and as such should be retained in the dataset. Retaining sites that have been resampled provides greater power for statistical assessment of trends. Removal of a site can be considered if the site undergoes land use change, or access is no longer possible. If a site is removed and the number of sites for that land use type is below the minimum number of sites, then the site should be replaced with a new site on the same land use type.

Replacement of sites

Of the 96 sites that have contributed to the programme since inception in 2000, five sites have subsequently been removed (i.e. sampling is not possible for various reasons). Additionally, a number of sites retained in the monitoring programme have been retained under the new land use type (e.g. sites changing from pasture to vineyard). This is acceptable and can provide useful information for assessing soil quality associated with land use change.

The main impact on the monitoring programme has been a decrease in the number of sites for some land uses, below what would be considered a minimum number of sites to detect soil quality changes with some certainty.

The replacement of sites should be considered if the number of sites for a land use type is below the minimum recommended number of sites, with some priority given to more intensive land use types. If possible, it is logistically best to add in replacement sites in the year they become inactive.

If new land uses are established in the region, then representative sites could be considered for adding to the soil quality monitoring programme but existing sites on other land use types should not be reduced to accommodate the additional sites.

Programme considerations

The logistics of maintaining a soil quality monitoring programme with annual sampling needs to be considered. In most cases resource availability (staff time and costs) will determine the size of the monitoring programme. For the MDC soil quality monitoring programme, an average of 20 sites per year have historically been sampled, with the current programme consisting of 91 sites. A monitoring programme with 123 sites seems most realistic for the Marlborough region and should provide an adequate indication of soil quality and trace element state and trends over time.

Using the land use types as the basis for stratification, a soil quality monitoring programme of 123 sites is suggested to provide improved precision for the detection of long term soil quality trends. The monitoring programme would provide an adequate minimum of 25 sites for each of the more intensive productive land use types (horticulture, cropping and dairy), 20 sites for each of the less intensive productive land use types (drystock and exotic forest), and 8 reference sites on indigenous vegetation, covering the most common soils in the region (**Table 11**).

Table 11. Example number of sites and their distribution across land uses for soil quality and trace element monitoring programmes.

National reporting land use type	MDC land use type	Current sites	123 site programme	160 site programme
Cropping	Cropping	12	25 (+13)	30 (+18)
Dairy	Dairy	26	26	30 (+4)
Exotic forest	Exotic forest	7	20 (+13)	30 (+23)
Horticulture	Vineyard	25	25	30 (+5)
Indigenous vegetation	Indigenous vegetation	4	8 (+4)	10 (+6)
Drystock	Pasture	17	20 (+3)	30 (+13)
Total		91	123 (+33)	160 (+69)
Average sites sampled/year using 5 year interval		18	25	32
Regional density of sites (sites/km ²)		0.007	0.010	0.012
Regional density of sites (km ² /sites)		137	101	78

Increasing the number of sites to 123 would provide some increased confidence in the data over the longer term. This would require the addition of 33 sites to the programme. Increasing the sites to 160¹⁰ to provide an optimum number of sites for each land use type (excepting indigenous vegetation) would provide improved confidence in the data and allow for more robust reporting but would substantially increase the cost of the monitoring programme, with 69 additional sites required.

¹⁰ Based on 30 sites for intensive land use types, 25 sites for less intensive land use types, and 10 reference sites on indigenous vegetation is close to the minimum number of sites required for detecting $d = 50\%$ in the power analysis.

Conclusions

- The MDC soil quality monitoring programme is soundly based, following nationally agreed methods.
- The number of current sites is low compared with other regional monitoring programmes.
- Based on the current number of sites, the MDC soil quality monitoring programme is unlikely to provide a suitable precision for detecting long term trends for most soil quality indicators.
- Increasing the number of sites for land use types (excluding indigenous vegetation) to an adequate minimum of 20 to 25 sites per land use type would improve the precision of detection for assessing long term changes in soil quality.
- Increasing the number of sites for indigenous vegetation to eight sites would provide 'reference' sites for the main soil orders across all land use types.
- A monitoring programme with a minimum 123 sites would be practical, provide more adequate data for assessing long term trends, and provide a monitoring programme more comparable with other regions.
- A monitoring programme with a minimum 123 sites would require the addition of 33 sites if all current sites were retained.

Recommendations

- Continue to monitor soil quality in the Marlborough district, resampling between 20-30 sites annually to maintain sufficient data for assessing long term soil quality trends in the region.
- Increase the minimum number of sites in the monitoring programme to an adequate minimum of 20-25 per land use (excluding indigenous vegetation) depending on the intensity of land use types.
- Increase the number of sites for indigenous vegetation to eight sites to provide 'reference' sites for the main soil orders across all land use types.
- Additional sites should be prioritised towards the underrepresented soil orders for each land use to improve the representation of the main soil orders within each land use type.

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