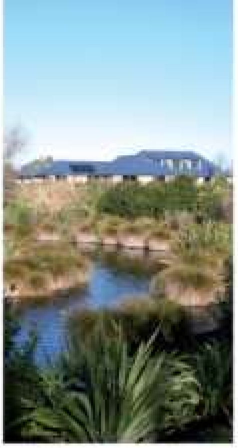

# Soil Quality and Stability Programme for Southland

Landcare Research
Manaaki Whenua

# Soil Quality and Stability Programme for Southland


**Scott Fraser, Bryan Stevenson**

*Landcare Research*


*Prepared for:*

**Environment Southland**

Cnr Price St and North Rd, Invercargill
Private Bag 90116, Invercargill 9840
Invercargill 9840
New Zealand

**December 2012**


*Landcare Research, Gate 10 Silverdale Road, University of Waikato Campus, Private Bag 3127, Hamilton 3240, New Zealand, Ph +64 7 859 3700, Fax +64 7 859 3701, www.landcareresearch.co.nz*

| | |
|---|---|
| *Reviewed by:* | *Approved for release by:* |
| Allan Hewitt<br>Senior Scientist<br>Landcare Research | Alison Collins<br>Portfolio Leader<br>Characterising Land Resources |
| *Landcare Research Contract Report:* | LC 1161 |

**Disclaimer**

*While every effort has been made to ensure the accuracy of the information provided in this report, no warranty or representation is provided regarding the accuracy of such information, and Landcare Research does not accept liability for any losses or damage arising directly or indirectly from reliance on the information.*

# Contents

# Summary


### Project and Client

- Environment Southland (ES) has requested that Landcare Research work with the council to develop a soil quality (SQ) and soil stability (SS) monitoring programme suitable for deployment in the Southland region. Over the coming years ES will establish and sample SQ monitoring sites throughout the region to best represent key land use and soil types in the region. Monitoring of SS will be incorporated into the programme and will utilise digital orthophotograph interpretation rather than field sampling methods to assess SS.
- The SQ and SS monitoring programme, alongside other monitoring programmes, will be used to inform and report on Southland's state of the environment (SoE).

### Objectives

The overarching objective of this current project is to help design a programme suitable for Southland that is consistent with guidelines for SoE monitoring and reporting, and in particular that the programme be scientifically robust and takes into account the needs of the Southland region (e.g. distribution of sites relevant to the soil types and land uses of the Southland region).

- Provide statistically robust and logistically feasible sampling programme across Southland that meets objectives of Southland SoE reporting requirements
- Provide and price two monitoring scenarios
- Identify limitations of proposed monitoring design
- Summarise SQ in Southland from existing data

### Methods

- The land monitoring forum (LMF) has agreed on seven key SQ indicators suitable across all major land uses in New Zealand.
- Additional SQ indicators should be considered in specific circumstances.
- To reduce set up costs and utilise existing soil data, new SQ sites should be established where possible beside soil profile points from topoclimate surveys or suitable NSD or LUCAS sites.
- The number of SQ sites needed to ascertain a specific level of change between sites can be calculated from the national data set. Sites will be chosen to represent broad combinations of land use and soil, with consideration given to climatic zones and sensitive environments.
- Distribution of soil quality sites are matched to the predominant soil types and land uses (largely pastoral) in the region.
- Soil quality sampling to be carried out at the same time each year, and include archiving of sub-samples.

- Each SQ site and a representative soil profile will be described in detail.
- Trace element analysis to be done in association with SQ analysis.
- Soil stability monitoring methods will be based on the methods outlined in Chapter 4 of the LMF guideline, and will use airphotograph interpretation from a grid overlaid on digital orthophotos.
- Field validation of a sub-set of SS sample points.

## Results

- Landcare Research endorses the recommendations for SoE monitoring outlined by the LMF and, based on this, provides two monitoring scenarios for ES to consider.

## Conclusions

- Soil quality and SS methods have been developed and used in New Zealand for a number of years. The LMF has compiled detailed guidelines so regional councils can implement comparable monitoring programmes throughout the country. Two scenarios for SoE monitoring, based on LMF guidelines and a review of SQ and SS monitoring in New Zealand, are provided for ES to consider.

## Recommendations

- Environment Southland consider the review of SQ in this document and assess the methods outlined below before deciding on a SQ and SS design for Southland.
- Environment Southland reviews both monitoring scenarios and chooses the most appropriate design for the budget they have allocated. This may involve removing pieces from both scenarios to tailor the most cost-effective programme for the region.
- Environment Southland should continue monitoring existing SQ sites; however, all future sampling (new and existing sites) should be done at the same time of the year when soil conditions are optimum for collecting intact cores.
- Use of existing data from previously sampled and/or described sites such as from LUCAS and NSD should be considered in SQ site selection. Landcare Research can provide relevant data on request.
- Soil stability should be monitored on a regular basis at an intensity that allows robust comparisons to be made temporally and on all major (> 1% by area) land uses.
- Where possible, but keeping in mind the integrity of this programme, Environment Southland should align SQ and SS monitoring with other SoE monitoring in Southland, particularly ground-water monitoring.

# 1 Introduction

Under section 35(1) of the Resource Management Act 1991(RMA), regional councils have an obligation to monitor and report on the state of the whole or any part of the environment in their regions to the extent that is appropriate to enable it to carry out its function effectively under this Act. State of the Environment (SoE) monitoring uses environmental indicators to monitor the effects of human activities on the environment (Land Monitoring Forum 2009). Environment Southland (ES) has requested that Landcare Research work with council to develop a soil quality (SQ) and soil stability (SS) monitoring programme suitable for deployment in the Southland Region. Over the coming years, dependent on financial and staff constraints, ES will establish and sample soil quality (SQ) monitoring sites throughout the region to best represent key land use and soil types in the region. Monitoring of SS will be incorporated into the programme and will utilise orthorectified aerial photo interpretation rather than field sampling methods for assessing SS. The SQ and SS monitoring programme, alongside other monitoring programmes, will be used to inform on Southland's SoE.

The overarching objective of this current project is to design a programme suitable for Southland that is consistent with national guidelines for SoE monitoring and reporting, and in particular that it be scientifically robust.

A Sustainable Management Fund project (500 Soils Project) was initiated in 1999 to select sites and collect SQ data that would be useful to gain an understanding of soil quality at a national scale. Participating regional authorities selected representative sites to provide SQ data in their region. Since the end of the 500 Soils Project, regional authorities have continued to establish and monitor SQ sites, with the number of established sites nationally now exceeding 800 (Stevenson et al. 2012). However, Stevenson et al. make the point that the dataset is not spatially uniform. The initiation of a SQ programme in Southland will go some way to addressing this issue and providing SQ sites that best represent Southland soils and land uses.

The SQ programme for Southland will incorporate cross-sectional monitoring (compare points in space) and trend monitoring (compare temporal changes). In order to simplify and keep the programme cost effective, only the most important soil/land-use combinations for the region will be monitored. However, two scenarios will be presented so that ES can consider the best combination of SQ and SS methods appropriate for the budget they have for SoE monitoring.

As pastoral land uses are by far the most important managed systems for SQ in Southland, a SQ monitoring programme should focus on these land uses. Generally, sites once established will be re-sampled on a 3–5 year cycle, although timing may depend on factors such as land-use type (e.g. forestry sites may have a substantially longer cycle), land management and climatic factors at the time, and emerging environmental priorities. Finding new sites will likely be ongoing after the initial establishment phase (approximately 5 years) as funding allows, due to loss of existing sites, for example, when land use or land ownership changes, which may mean some sites are no longer suitable for ongoing monitoring. It is important that a monitoring programme is flexible enough to cope with changing land use and ownership/accessibility.

Soil stability (SS) will be part of the monitoring programme, it will be based on guidelines published in chapter 4 (Burton et al. 2009) of the Land and Soil Monitoring Guide, and will use orthorectified aerial photographs to assess soil stability across the region. The assessment of SS is likely to be on a 5-yearly timescale; although for 'hot spots' it may be desirable to monitor more frequently if images are available.

Environment Southland already has established 10 pastoral SQ sites that will be incorporated into the SQ monitoring programme. A summary of SQ at these sites is presented in Appendix 2.

# 2 Background

While SoE reporting is currently not mandatory for national level reporting, under the RMA regional authorities are required to monitor and report on the environment in their region in order that they can carry out the functions required of them under the Act, that is: *"to achieve integrated management of the natural and physical resources of the region"*. SoE reporting is required to:

- raise awareness of the state of the environment
- improve ability to report environmental health and trends
- provide tools for evaluating policy
- form the basis for more informed policy and management decisions.

Environmental indicators are used to inform on the state of the environment, and the Pressure-State-Response model (PSR) was developed by the OECD as a framework for choosing environmental indicators that provide information on the state of (state indicators) and pressures on (pressure indicators) the environment. While this report outlines a programme for monitoring state trends, it should be mentioned that it would be important to monitor pressure trends to keep up with such changes as land use and intensity, as well as climate (Land Monitoring Forum 2009). There has been recent discussion to incorporate SQ monitoring into a larger "soil and ecosystems services" framework. Current thought is that the PSR model would fit within this framework and at present we do not anticipate significant changes to the SQ methodologies.

Literature on soil monitoring for SoE purposes uses the terms 'soil quality' and 'soil health', often interchangeably, but the terms are often not well defined. For the purposes of this report the term 'soil quality' refers to measurements of qualities or attributes of soil that can be quantified, but that do relate to the concept of soil health in the sense that health refers to the biological component of soil. It is important to make this connection as soil quality endeavours to make quantitative assessment of the soil's fitness to support plant, animal, and human health.

The Southland Region covers an area of approximately 3.1 M ha, 95% of which is on the mainland, the remainder on Stewart Island and other smaller inshore islands. A considerable area of the Southland Region is also taken up by Fiordland National Park – 1.26 M ha. Over 50% of the region is in indigenous vegetation – forest, scrub or tussock (Figure 1). Monitoring of SQ will focus on managed productive land – pasture, arable and forestry –

although indigenous sites will be incorporated mostly as reference sites to provide baseline data to compare with productive agricultural and forestry land.

The extent of a SS monitoring programme will need to be decided by ES depending on their SoE requirements; however, two scenarios will be presented for consideration.

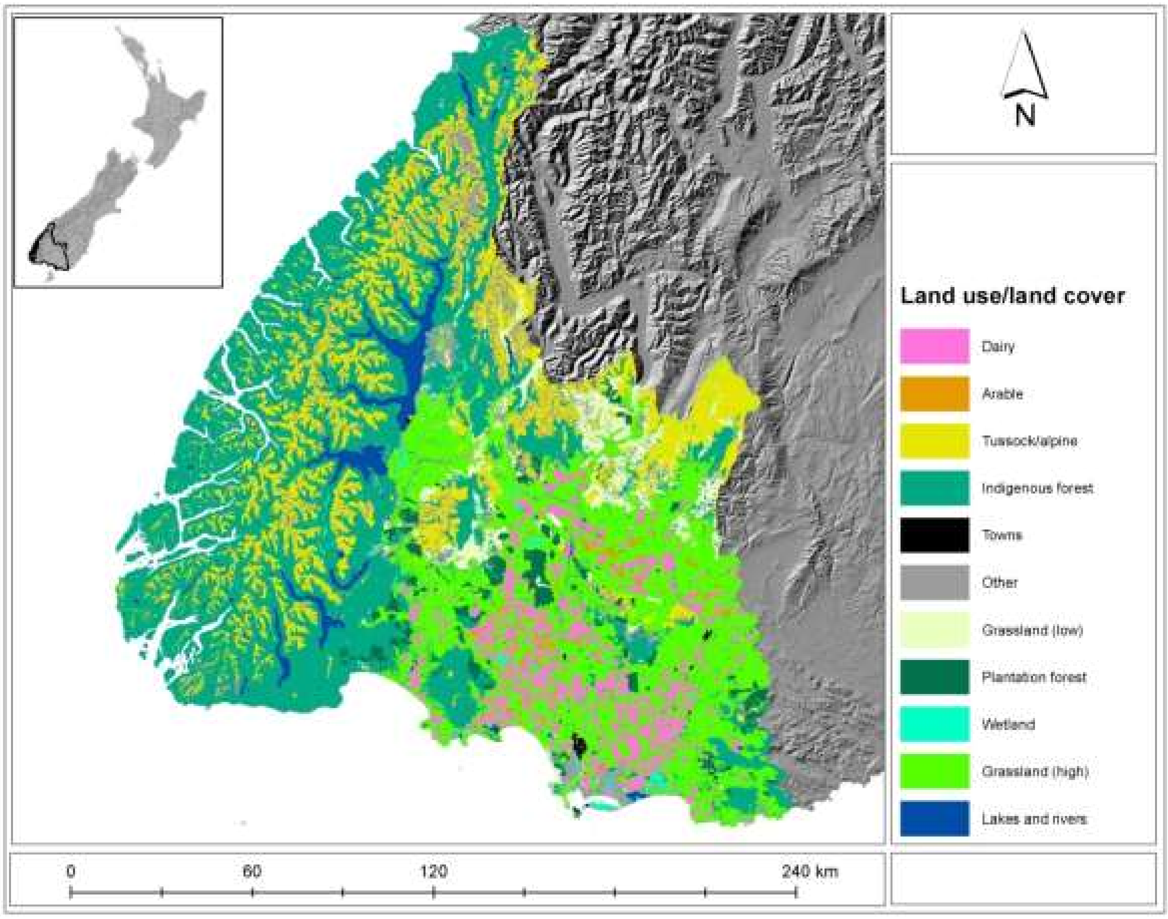


**Figure 1** Spatial extent of different land use/land cover classes in Southland (data from LCDB3, FAR, ES).

Soils are diverse across Southland and reflect the recent geological/climate history of the region, with steep hills and mountains surrounded by broad alluvial plains. Brown soils (Hewitt 1995) are the predominant Soil Order across the whole region (Figure 2). Across the plains and lowlands, Pallic, Gley and Recent soils are common, reflecting stable loess surfaces, poorly drained areas, and recent floodplains respectively. There are small areas, but significant in terms of agriculture and sensitive environments, of Organic soils, mostly in low-lying coastal areas. Melanic soils are also significantly distributed in the hill country of central Southland (Hokonui Hills and adjacent to the Waimea Plains). Podzols make up a significant proportion of the elevated high rainfall areas of Southland, but are of less significance to farmed areas.

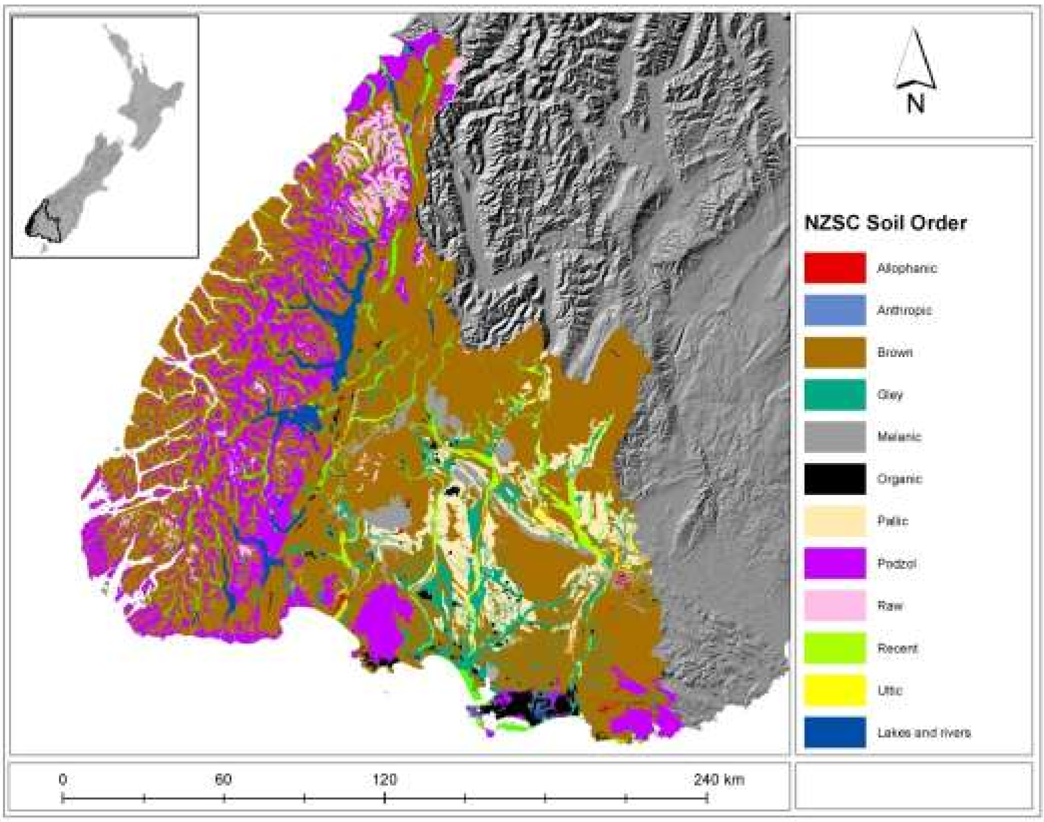


**Figure 2** Soil distribution across Southland (data from FSL + Topoclimate soils).

Productive land use by area in Southland is predominantly pastoral, with low-intensity dry stock accounting for the largest area, while high-producing pasture (dry stock and dairy) likely account for the majority of stock units in the region (Figure 3). It is difficult to separate intensive land use by stock type or in terms of arable use, as data are inconsistent. Data from LCDB3 vegetation, ES dairy, and the Foundation for Arable Research (FAR) have been used to estimate areas in different intensive land uses. The issue is complicated by the fact that multiple land uses often occur on a single land holding, particularly with arable cropping.

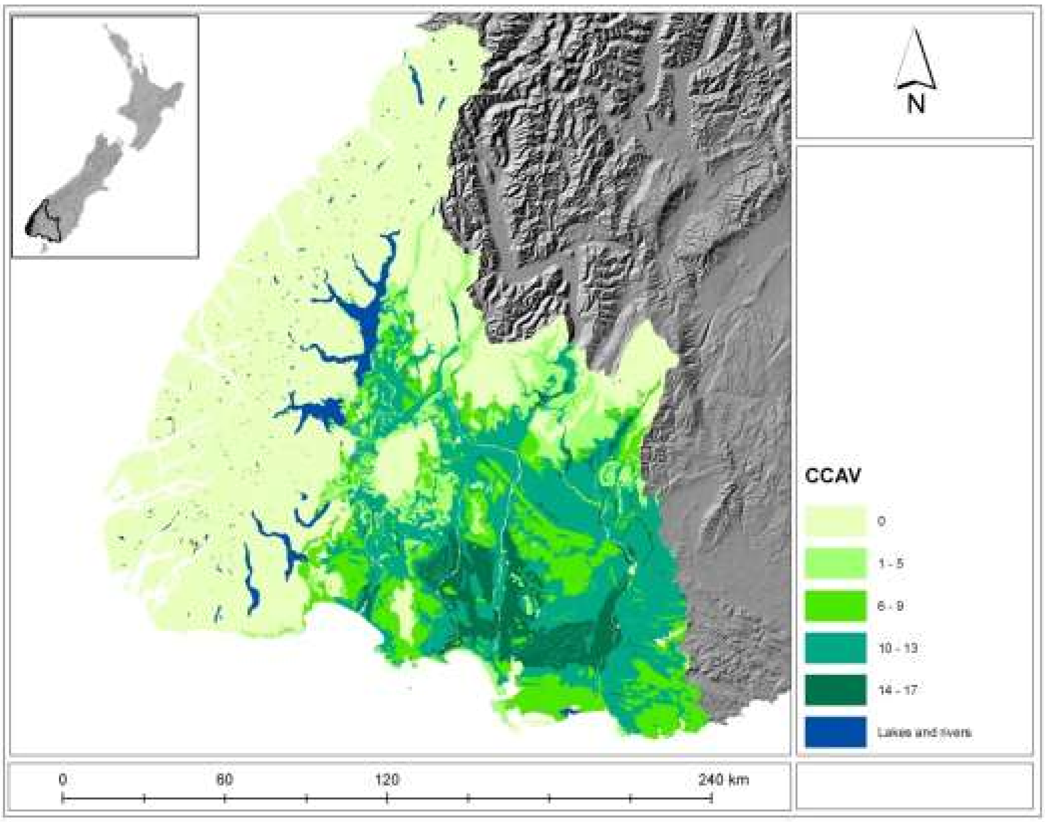


**Figure 3** Estimated average stock carrying capacities (CCAV) from LRI (note: data based on 1970s/1980s carrying capacities).

## 3 Objectives of soil quality and soil stability monitoring

The objectives of a soil quality (SQ) and soil stability (SS) monitoring programme for Environment Southland (ES) are to:

- provide information on soil physical, chemical and biological properties to enable an accurate assessment of soil quality within Southland
- enable spatial and temporal changes in SQ and SS to be evaluated across key soil and land-use types in Southland
- assess the effects of land use and environmental influences on the quality and stability of Southland's soils
- provide an early warning system to identify pressures on soil quality, quantity and the environment
- provide a mechanism to measure the effects of regional and national policy and best practice implementation on soil quality parameters
- highlight knowledge gaps in the state and trend of the regions soil quality to enable more complete monitoring to occur in the future
- design a monitoring network that can complement other national datasets and other regional councils data.

# 4 Review of soil quality

A review of current SQ and SS monitoring methods being used in New Zealand was undertaken to ensure a programme was developed for ES that was compatible with national SoE monitoring and reporting and consistent with other regional councils. For background on SQ and SS refer to relevant sections in Land Monitoring Forum (2009).

Soil Quality monitoring for SoE reporting purposes started in the late 1990s in New Zealand (Trialling Soil Quality for SoE Reporting), but did not substantially progress until an incentive was provided by the Ministry for the Environment in 1998 for regional councils to start SQ monitoring programmes; a requirement of which was the development of a consistent methodology which would allow SQ to be compared across regional boundaries (Sparling & Schipper 2002). This was the beginning of work that led to the establishment of the '500 soils dataset', which forms the basis for SQ monitoring in New Zealand.

A set of seven SQ indicators (total C, total N, pH, Olsen P, mineralisable N, bulk density, and macroporosity) were eventually selected from a larger set of indicators that Sparling and Schipper (2000) had previously investigated. This minimum indicator set was based on those dynamic soil properties that were best able to provide meaningful interpretation of biological (related to soil organic matter reserves), fertility, chemical and physical qualities of soil under a range of land uses and soil types relevant to New Zealand, while also being cost effective (Sparling et al. 2004). As such, the system was meant as a general indication of soil quality and an early warning system to identify pressures on soil quality. Target values were decided on by "expert opinion" of a representative group of New Zealand soil scientist (Sparling et al. 2003). The target values attempt to balance optimal levels of nutrients for agronomic production against the environmental consequences of excess nutrients in the environment. Poor performance of specific soil quality indicators may need further in-depth study to determine the cause and extent of these pressures. It must also be noted that soil quality is a subjective assessment, and no universally accepted procedures or indicators exist. However, the 500 soils approach is used by several regional councils for SoE reporting and is based on data published in peer reviewed international scientific journals (e.g. Sparling & Schipper 2002; Sparling et al. 2004).

The 500 soils dataset was biased for a number of reasons:

- not all regional authorities participated
- participants had differing views on monitoring: should monitoring target at risk land use in a region, or provide a nationally representative dataset
- over-representation of some soil land-use combinations, and under representation of other based on regional distributions.

This has implications for current regional SoE monitoring as councils must decide what is appropriate for their region (rate payers), while endeavouring to provide datasets useful for SoE monitoring purposes.

A review of SQ indicators after 12 years of monitoring in the Waikato Region (Taylor et al. 2010) concluded that the existing key SQ indicators were useful for SoE monitoring in the region and were able to define five key regional issues of SQ: soil compaction; topsoil organic matter decline; excessive fertility; erosion risk; and accumulation of contaminants. It is arguable, however, how well SQ indicators do relate to erosion risk (Les Basher, Landcare Research, pers. comm.). The review questioned the target limits set for some indicators, specifically that the upper limit for Olsen P was set too high to protect water quality, the lack of a suitable indicator to define environmental limits for N, and the usefulness of the mineralisable N indicator.

# 5 Methodology

## 5.1 Soil Quality (SQ) Indicators

The land monitoring forum (LMF) has agreed on seven key SQ indicators suitable across all major land uses in New Zealand. The following indicators are used widely for regional SQ monitoring in New Zealand and are recommended for SQ monitoring in Southland under all land uses:

- bulk density (BD)
- macroporosity (at –10 kPa)
- total carbon (TC)
- total nitrogen (TN)
- Olsen P
- pH
- anaerobic mineralisable nitrogen (AMN).

In addition to these seven key indicators, it is suggested that additional indicators be considered in specific circumstances. On cropping and horticultural sites it is recommended that aggregate stability is included as an indicator. If stony soils are included in the SQ monitoring programme, aggregate stability may be a useful alternative to macroporosity where intact soil cores are difficult to obtain. P retention is useful for understanding Olsen P levels and would be worth including on agricultural sites; as it is an inherent soil property, P retention would only need to be assessed once at a site.

The SQ indicators listed above do not include direct biological indicators as such, although the three C and N indicators do relate to biological activity, AMN in particular correlates reasonably well with microbial biomass C (Sparling et al. 2004). Recent research suggests that hot water C (HWC) may provide as good or better estimate of microbial biomass C than AMN and would be worth considering as an alternative or addition to AMN. An advantage of HWC over AMN is that it is may be a more cost-effective alternative; however, it would be recommended (for comparative purposes) in addition to rather than as an alternative to AMN until the method is more widely used and target values are defined. Schipper and Sparling (2000) tested microbial indicators that may be useful for SQ monitoring (microbial biomass C, soil respiration), but concluded that these indicators were temporally highly variable, did not necessarily give clear indications of microbial health, and would be therefore difficult to interpret or to set meaningful targets. However, some councils are measuring microbial biomass and respiration as part of their SQ programme. Work has continued to investigate possible microbial indicators (Stevenson & Fraser, unpublished) for SQ monitoring, but at this stage a useful indicator method has not been developed; however, it is recommended that ES consider including a microbial indicator in the future if and when a suitable method be developed.

Changes in soil C and N stocks is an emerging issue in New Zealand (Schipper et al. 2010), with indications that intensively grazed pasture systems, particularly dairy, may be losing significant C and N stocks from the profile. It would therefore be worth considering more detailed monitoring of these stocks under intensive pastoral systems. Sampling from 0 to 30 cm in 10-cm increments could be included for intensive pastoral sites to get a better estimate of per hectare changes in C and N stocks. Statistically robust, cost-effective methods to determine stocks and changes in soil profile C and N are currently being developed in collaboration with Landcare Research. On-going work is also investigating whether the ratio of N15 to N14 can be used as an indicator of long-term N cycling and loss in pastoral systems.

While Olsen P is the most widely used measure to estimate plant available P, it does have limitations. Olsen P does not give a good estimate of plant available P for forestry crops; if this is considered important (i.e. below target range) a more appropriate measure of P availability to trees would be total P. Additionally, it is recommended that ES use the gravimetric method used by Landcare Research, however, consideration needs to be made when comparing analyses made with this method and that commonly used by the fertiliser industry where they use a volume based method (not to be confused with volumetric, where P stocks can be estimated from intact bulk density cores).

## 5.2 Site Selection

Ten pasture-monitoring sites have already been established, and it is recommended these be included in the new SQ monitoring programme. To reduce set-up costs and utilise existing soil data, where possible new SQ sites should be established beside soil profile points from topoclimate surveys or suitable NSD or LUCAS sites. To be suitable, these profile points need to be located in the same land use as the SQ transect (i.e. roadside and track cutting not suitable), representative of the soil across the transect, and on a similar slope and aspect to the transect. A list of potential NSD and LUCAS profile points are presented in Appendix 1.

Comparison of paired land-use sites can statistically be more powerful than comparing sites randomly chosen throughout the landscape. Where feasible, paired site comparisons are encouraged, but care is necessary to set up proper paired site comparisons (i.e. where all soil factors but land use are similar) and to obtain sufficient replication of paired sites to make adequate statistical comparisons. Comparisons between intensive and extensive pasture or pasture and cropping are often the easiest paired site comparisons to make.

The number of sites needed to ascertain a specific level of change between different land uses or between different soil classes (or the deviation of a single site from the mean for that soil class or land use) can be calculated from the national data set (Stevenson et al. 2012; Hill et al. 2003); however, variability at the national level will not necessarily be of the same magnitude as variability on a regional level. The general recommendation has been for a minimum of 30 sites of each land use (Hill et al. 2003), though from past sampling in other regions we have been able to detect statistically significant change in soil quality indicators over time when 10 sites (or more) are aggregated by land use. Site selection encompasses a trade-off between representation of land use and soil type compared with their proportional land coverage, versus minimum sample size in each of the soil and land use categories. We present two sampling scenarios and, in consulting with Southland, we will determine the land uses and soils types of most concern.

Consideration should be given to other SOE monitoring in Southland and where possible align new SQ sites with existing SOE monitoring. Groundwater monitoring is the most likely to align with SQ, and ES should investigate where SQ sites might be correlated to groundwater monitoring sites; that is where groundwater origin can be linked to a certain soil type or a defined area.

Some guiding principles when considering sites for selection would be:

- Representativeness – within a paddock, a farm and within a land use
- Stability – consider site erosion, disturbance, flooding, and irrigation as these factors may confound results
- Land use and management consistency may be worth considering but difficult to predict into the future
- Access to management data – how well informed and cooperative is the land owner/manager, including records of past management practice.

### Pasture Sites

It is recommended that sites be chosen to represent broad combinations of land use and soil. Consideration should also be given to climatic zones; however, to keep the system simple it is suggested just two climatic zones are used: broadly speaking a coastal zone and an inland zone, roughly dissected by the Hokonui Syncline. For certain land-use/soil combinations a division of the coastal zone may also be warranted – this is a narrow strip (10–20 km) of lowland immediately adjacent to the coast that includes some particularly sensitive environments (wetlands) and soils (Organic, Recent, Gley, Podzol).

Sites should be chosen in either of these climatic zones based on the predominant soil/land-use combinations found there, for example dairying mostly occurs in the coastal zone (i.e. south of Hokonui syncline) - Table 1. Dry stock has been divided into intensive and extensive; however, it is difficult to define the differences between extensive and intensive pastoral land use. The idea is that intensive dry stock is similar in many ways to dairy land use, and it is therefore useful to discriminate between this and less intensive dry stock. For the purposes of this SQ monitoring programme it is suggested that intensive dry stock are dry-stock farms that focus on fattening/finishing livestock as well as other intensive grazing systems such as dairy grazing, and occur on flat to easy rolling land, while extensive dry-stock farms will focus on breeding stock farms and be predominantly situated in hill country. In addition to the soil Order stratification, extensive dry-stock sites should also be broadly representative of the predominant LUC slope classes they occur on – rolling to moderately steep slopes (slope classes C, D and E). Intensive pastoral land use is less likely to be influenced by slope as most land is likely to be $< 15^{\circ}$. In Table 1 below, extensive dry stock has not been divided into coastal and inland, as there is unlikely to be such a clear distinction as is possible with the more intense land use. For extensive dry stock it is suggested that sampling represents the main hill country areas of Southland as represented by Figure 4 showing the LUC slope classes predominantly > 10˚. These can broadly be described as south-western, south-eastern, central and northern hill country regions. While extensive land use is predominantly in hill country, SQ sites should be situated on easier slopes within hill country to avoid erosion processes confounding SQ data. Care must also be taken when selecting representative sites in hill country to avoid stock campsites where physical and chemical properties may not be generally representative of the land use.

For the purposes of reporting, pastoral land uses can be separated as outlined (i.e. intensive vs extensive), but for compatibility with SQ reporting in other regions, both drystock classes could be combined for reporting; alternatively, comparisons could also be made between intensive and extensive pastoral land use by combining intensive dry stock with dairy.

The major Soil Orders under pasture – Brown, Pallic, Gley, Recent, and Melanic – do not vary greatly by climatic zone; however, they do vary by land use so it is recommended that sites be chosen to represent this. A suggested land use/soil combination is presented in Table 1. While Podzols have not been identified as an important soil under agricultural land uses, there may be significant areas, particularly in coastal hill country, that have not been identified from either the topoclimate or FSL layers interrogated during this project as only the dominant soil by polygon was assessed. It may be worth considering including a small number of Podzols under extensive dry-stock pasture for comparison with Podzols under indigenous and exotic forest land uses. Alternatively, Acid Brown soils, particularly Placic Brown soils (e.g. Scrubby Hill series) that are closely related to Podzols, could be included as one of the Brown Sub-groups.

### Arable Sites

From the data available it is estimated that arable land use accounts for less than 1% of the agricultural land-use area; however, accurate statistics are difficult to obtain, partly due to the definition of this land use. Intensive arable cropping (or market gardening) can negatively impact on soil quality, and particularly on soil C levels. Cropping generally makes up only a small percentage of land area in New Zealand, thus the intensity of cropping and its impacts must be weighed against the land area impacted. In Southland the majority of arable crops are grown as fodder crops for winter grazing by livestock, and generally are part of a crop rotation that may be predominantly pasture. It is estimated (George Ledgard, Environment Southland, pers. comm.) that approximately 10% of intensive pasture land may be in crops at any one time, and therefore cropping does play an important role in intensive land use. Due to the problems of finding and establishing permanent long-term arable monitoring sites it is recommended that ES monitor arable cropping as part of the intensive pastoral monitoring programme. However, if some permanent sites can be located these would be valuable to compare between long-term cropping and cropping/pasture rotations. When monitoring cropping sites in paddocks that go through a cropping rotation, but are considered predominantly pastoral, it will be important to record time since cultivation at each sampling time as well as the total number of years the site has been cropped in the previous 10 years. It is suggested that 10 long-term arable sites be included in the SQ monitoring programme, to correspond to a similar number of pasture/arable sites from the pasture SQ sites.

**Table 1** Suggested percentage of SQ sites by land use/climatic zone and soil Order for pastoral land use sites. This table is intended as a guideline for selecting pasture SQ sites based on estimated frequency of soil/land use distribution in Southland; however, data came from a combination of sources including ES, topoclimate, FSL and LCDB3

| Land use | Brown | Pallic | Gley | Recent | Organic | Melanic | Total |
|---|---|---|---|---|---|---|---|
| Dairy coast | 9 | 5 | 5 | 2 | 3 | | 24 |
| Dairy inland | 5 | 4 | 4 | 2 | | 2 | 17 |
| Intensive Dry stock coast | 6 | 4 | 4 | 2 | 3 | | 19 |
| Intensive Dry stock inland | 4 | 4 | 3 | 4 | | 2 | 17 |
| Dry stock extensive | 12 | 8 | | | | 3 | 23 |
| Total | 36 | 25 | 16 | 10 | 6 | 7 | 100 |

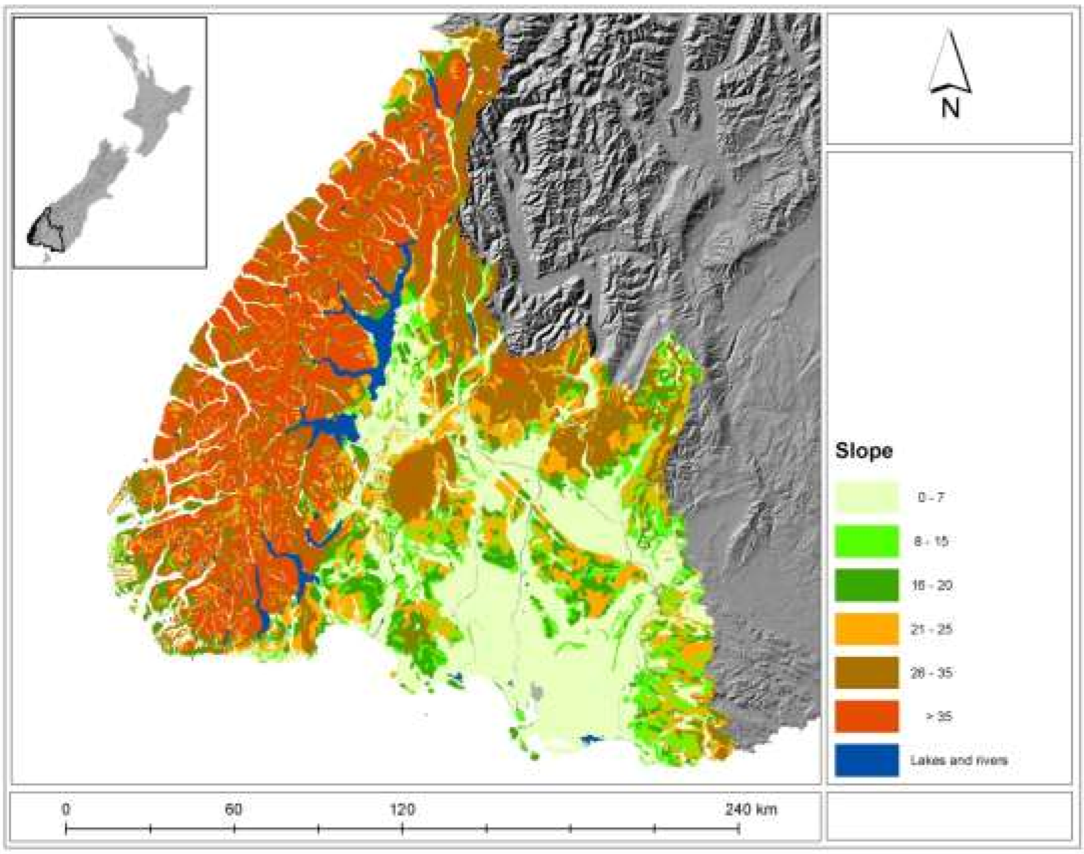


**Figure 4** Modified slope classes from the LRI – slopes classes C+A and C+B have been included in the 0–7 slope class to better represent areas of flat and undulating land.

### Forestry Sites

Exotic forestry covers less than 3% of Southland, or approximately 7% of the managed land uses – agriculture + forestry. While this is not a major land use in Southland, it does have some environmental issues associated with harvesting and replanting that warrant this land use having a limited number of monitoring sites. The majority of exotic forests are established on LUC class 6 land (with a few on class 7) and most of these have an erosion limitation. Most of the remaining exotic forestry is situated on LUC class 3 and 4, with a soil limitation. Brown soils account for most of the area under exotic forestry; however, in some areas there are significant areas of other soil Orders. Around the Hokunui Hills Melanic and Pallic soils are mapped under forestry; in the Catlins and Longwood forest areas Podzols may be significant; while there are also areas with Recent soils on coastal sands and river terraces.

As the number of soil Orders represented under forestry is small, a lower number of forestry sites may still be adequate to provide a robust forestry SQ dataset. It is recommended that a total of 10–20 forestry sites are selected with 60% Brown and 20% Podzol on LUC class 6 land, with the remaining 20% on Recent soils on LUC class 3s or 4s. Forestry sites should be sampled to fit in with harvesting and re-planting rotations. A suggested sampling regime might be mid-rotation and after re-planting before canopy closure.

### Indigenous Vegetation Sites

Over 50% of Southland remains in indigenous vegetation, which includes forest, scrub, and tussock. While this is the main land use in the region, this land is mostly managed as conservation estate and therefore management is not an important consideration in SQ. As these sites serve as a baseline against which to compare other land uses, and as there are unlikely to be significant changes in SQ attributes over short time frames, it is suggested these sites do not need to be monitored as regularly as the other sites – possibly every 10–15 years would be sufficient.

Indigenous sites should be selected, mostly to provide baseline data to relate to agriculture and forestry land uses. It is suggested an equal number (up to 20 of each) of sites be selected in both forest and grassland/scrub vegetation types to represent indigenous vegetation best and also to be able to make more meaningful comparisons with agriculture and forestry land uses. Indigenous grassland/scrub sites should be situated on un-farmed land to be representative baseline sites. Based on personal communication with Ian Payton (Landcare Research), indigenous grassland/scrub sites could be selected from lowland red tussock reserves (most likely DOC land) and snow tussock land above the bush line, such as in the hills around the Waikia area.

The National Soils database (NSD) contains numerous entries from Southland, Central Otago, and South Westland (West Coast and Southland), and a search of the database found approximately 100 sites that had indigenous vegetation listed at the site, which was in or within 50 km of Southland. Most forest sites were in areas remote from road access in Fiordland National Park, while most sites with tussock and/or indigenous scrub appeared to be in grazing land. Most of these non-forested sites were also outside Southland in Central Otago. It is recommended that NSD sites with indigenous vegetation are not generally suitable for SQ monitoring sites for the reasons outlined above; however, a subset of these sites might be useful to form a background dataset of soil properties under indigenous vegetation to support the new SQ sites established. As it was not possible to distinguish whether or not tussock land cover was farmed in many areas, further consideration is needed before tussock background sites are selected.

## 5.3 Sampling

To achieve the best monitoring of temporal changes, sampling should be carried out at the same time each year, as some measured soil attributes have seasonal cycles of change. Sampling for physical properties requires optimum soil moisture to ensure good quality samples for analysis. It is recommended that sampling is carried out in late spring when soil reaches optimum condition for sampling – this may vary from season to season, and, as far as possible, it is better to sample by soil condition rather than a fixed calendar date. Optimum conditions are required for collecting intact cores for soil physical analysis; it is recommended that ES consult with soil physics laboratory staff to better understand requirements for collecting cores. Sites that have already been sampled should be sampled at the same time in the spring rather than continue to sample in winter as has been the case.

As outlined in the LMF guidelines, a sub-sample from chemistry samples should be archived. This is particularly important if future sampling results indicate elevated levels of trace elements and a more comprehensive suite is then analyzed. To understand accumulation and baseline concentrations archived samples may need to be re-analyzed for a more comprehensive suite of elements.

## 5.4 Site Descriptions

Once a SQ site has been selected following the method outlined in Hill and Sparling (2009), the site and soil profile should be described in detail, also outlined in Hill and Sparling. While it is recommended that both ends of the transect be marked with GPS it is also worth recording other details that will enable future accurate re-location, such as a detailed verbal description of the site location, compass bearing of transect direction, and whether the transect shape is not a straight line. Site photos, showing a tape measure across the transect, are invaluable for exact re-location, particularly if permanent features such as relief, buildings, trees, etc., can be incorporated into the picture.

### S-map

In addition to the profile description method of Milne et al (1995) (referred to in Hill and Sparling 2009), it is recommended that profiles be described in sufficient detail that the data can be used to identify them to the sibling level in S-map. S-map is the new spatial database for New Zealand soils and has been designed to meet modern demands for quantitative soil information (Lilburn et Al. 2011). S-map builds on the New Zealand Soil Classification (NZSC) of Hewitt (2010), and Soilforms of Claydon and Webb (1994), adding two new categories to the NZSC:

Soil Order – Group – Subgroup – family – sibling, e.g. Argilic Perch-gley Pallic (PPJ) Dipton_2.

The soil series name, while being retained where a soil is already named, is not used to define soils in S-map. Soils information can still be found in S-map by searching by series name; however, as there is no direct correlation between the series and family/sibling, a series name may relate to numerous different families and siblings that were historically given the same name. The advantage of S-map sibling information (S-map data are input and retrieved at the sibling level) over series information is that this information contains quantitative data and correlates soils anywhere in New Zealand based on objectively defined soil entities. If SQ sites are associated with topoclimate or NSD soil profile pit sites, profiles will already be defined in S-map. S-map will allow more accurate SQ site comparisons to be made not only throughout Southland, but also throughout the country as SQ site information is added to S-map. Recent work with Auckland Council has highlighted that historical data can be inadequate to define S-map siblings clearly; therefore it is recommended that relevant data be collected at the time of site establishment. Data required for S-map (Lilburne et al. 2011) relates to data entry to the sibling page of the database; the other pages relate more to spatial distribution of soil attributes in mapping units that is not applicable to single point data. Data required to define the sibling at a point are 1) NZSC, parent material, rock class, texture class, permeability class, rock of fines (to define family), and 2) depth class, top soil stone class, primary/secondary texture classes, drainage class, and a set of functional horizons (FH's) defined by morphological parameters (to define sibling).

At this stage sibling factsheets can be generated from S-map online, as long as they are associated with a mapping unit or contain spatial information such as ranges of attribute information, i.e. depth range, sand and clay % range of FHs across their spatial distribution. For SQ siblings, a factsheet will not be able to be generated unless the sibling has already been defined by these spatial attributes, that is, as part of a soil survey.

It is recommended that ES collect/use SQ site sibling data to give greater ability to define functional attributes of Southland soils. Stevenson et al. (2012) assessed data from over 800 SQ sites throughout New Zealand and confirmed Sparling et al.'s (2004) original findings from the '500 soils' dataset that Soil Order/land-use interactions explain between 40 and 60% of the variance of SQ indicators. One of the recommendations of Stevenson et al. (2012) was to assess more variable Soil Orders (Brown, Recent, Gley) in greater detail, such as at the Sub-group or S-map sibling level. Having detailed sibling data may allow much greater ability to explain differences between sites as well-defined physical and chemical data are available that had not been previously linked to SQ sites.

## 5.5 Trace Element Monitoring

Assessment of trace elements will be done in association with SQ analysis on the same samples collected for SQ chemical analysis. Trace element assessments are not recommended in isolation as other soil properties need to be considered. Trace element monitoring can include essential trace elements for plant and animal health, contaminant trace elements, and trace elements that affect the mobility and availability of other trace elements. Other elements, such as iron and manganese, can also strongly influence the behavior of trace elements and their measurements can therefore be useful to better understand trace element chemistry. The main trace elements of concern for SoE reporting are contaminant trace elements, and in Southland will be mostly associated with intensive pastoral land use and high fertilizer input, e.g. Cd, F, U (though F and U are not always analyzed for). Horticulture can have increased levels of other metals (particularly Cu or Zn). A basic suite of seven trace metals (As, Cd, Cr, Co, Cu, Pb, and Zn) is generally sufficient as an overall indication of trace metal content. If a greater range of metals is desired (for instance to tie in to water quality), additional metals can be included. Additionally, if high levels are found at particular sites, these sites can be investigated further (e.g. if Cd levels are relatively high then F and U could be analysed).

## 5.6 Soil Stability (SS) Methods

It is recommended that ES follow the methods outlined in Chapter 4 of the LMF guideline. The base year for the initial assessment will depend on the council having access to the appropriate images. Digital aerial photographs do exist for all parts of New Zealand; therefore, it is recommended that ES uses the most recent images that give full coverage of the region or part of the region that ES decide to monitor. Digital orthophotos need to allow accurate assessment of landscape features and Burton et al. (2009) recommend a pixel size no greater than 1 metre, thus allowing viewing down to a scale of 1:2500. It is recommended that field validation of a sub-set of sample points is carried out. Both Waikato Regional Council (Thompson & Hicks 2009) and Tasman District Council (Burton 2001) randomly selected 100 sample points for validation from a sub-set representing points within 100 m of a public road. In order to get a statistically robust estimate of SS in a region, Burton et al. (p. 97) provide a formula (Kolmogorov's formula) for calculating a preliminary estimate of required sample point size; however, they argue that from previous regional sampling surveys so long as total points exceeds 2000, error margins of +/– 2 standard errors at 95% confidence can be achieved. Environment Southland should consider what requirements they have for SS monitoring before deciding on an intensity and extent of monitoring. For example:

- Should the whole region be monitored?
- Should different parts of the region be monitored at different intensity?
- What would be the implications for reporting by land use or land cover should monitoring intensity not be consistent across the whole area assessed?
- Will SoE reporting on SS be by region, sub-region or zone?

The way these questions are answered will have implications for the intensity and extent of SS monitoring in Southland.

If the whole mainland area of ES was to be monitored then a 4 × 4-km grid (1600 ha/grid square) would provide approximately 1850 observation points. If Fiordland National Park was excluded then a 3 × 3-km grid (900 ha/grid square) would provide a similar number of observations. Tasman District Council have used a 1 × 1-km grid across non-DOC land in the region, which required 6005 observation points (1/100 ha), while GWRC and WRC applied a 2 × 2-km grid of their entire region, with 2039 and 6122 observation points respectively. Environment Canterbury has been monitoring 140 hill-country sites for up to 40 years using stereo photo transects (SPT).

If ES use a 3 × 3-km grid across the region (excluding Fiordland National Park), apart from some of the eastern area of Fiordland National Park, this would bring the entire dataset to over 2000 sampling points – likely enough to give a robust design. The points from eastern Fiordland National Park could be used to extrapolate to the rest of Fiordland. Alternatively it might be more desirable to use a different grid size (6–9 km) over the entire Fiordland National park to give a more representative sample.

Sampling frequency should be every 5 years (as a minimum every 10 years); however, for some high risk land-use/ land-cover categories more frequent sampling might be desirable, providing images are available.

# 6 Costs

Environment Southland has requested costing of two scenarios for a SQ and SS monitoring programme. Details given in the methodology section (5.2) are based on a maximal design, scenario I, while a minimal design, scenario II, is based on the same methodology but with a reduced sampling density/frequency. Essentially, scenario II SQ does not include arable land (apart from pasture sites that are occasionally cropped), horticulture, exotic forestry or indigenous grassland; however, the number of pasture sites is unchanged. A limited suite of trace elements are included in scenario II compared with more the extensive suite for scenario I. Details of costing for both scenarios are presented below.

## 6.1 Scenario I: Maximal Design

### Soil Quality and Trace Elements

Soil quality monitoring for scenario I recommends a total of 170 SQ sites across Southland to represent all important land uses in the region, these being defined as:

- Intensive pasture – dairy
- Intensive pasture – dry stock
- Intensive pasture/arable
- Extensive pasture – dry stock
- Horticulture
- Forestry – exotic
- Indigenous forest
- Indigenous grassland – not farmed

The soil/land use combinations have been discussed in section 5 above, Table 2 details SQ sites by land use. Costing has been split into field and laboratory costs. The field component has been split into phase 1 – site establishment and first time sampling and phase 2 – re-sampling. Establishment and sampling costs were based on personal communication with Mathew Taylor from WRC. Laboratory costs have also been split into SQ analyses and trace element analyses as these may been carried out on different sample numbers or at different frequencies. Trace element analysis costs are based on a multiple suite of 33 (includes chloride and uranium) trace elements plus fluoride, a non-standard method that requires extra set-up and analysis costs. Costings for trace element analysis were provided by Hill Laboratories in Hamilton, while SQ sample analysis is based on Landcare Research laboratory costs.

## Soil Stability

The maximal SS scenario for ES includes the entire mainland area and uses a 2 × 2-km grid across the region to assess SS at intervals of 5 years. Costs are based on time required for orthophoto interpretation and recording. Additional set up costs are not included – it is assumed ES already has images and GIS capability to set up the monitoring framework. The SS monitoring costs were based on personal communication with Reece Hill from WRC, and assuming 300 grid points per day can be assessed ($2/point). For scenario I, a 2 × 2-km grid across the whole mainland region would give approximately 7500 points at an estimated cost of $15,000 for SS assessment (Table 4). Further analysis and reporting costs have also not been included, but for comparison, WRC budgeted between $25,000 and $30,000 all up for SS in the Waikato region every 5 years (Reece Hill, Waikato Regional Council, pers. comm.).

**Table 2** Scenario I costing based on number of sites selected. Cost of establishment and first sampling (phase 1) separated from re-sampling (phase 2). Laboratory analysis costs are the same for both phases

| Land use class | Sites required | Establishment and sampling cost ($500/site) at 2 sites/day | Re-sampling cost ($250/site) at 4sites/day | Lab. analysis for 7 SQ indicators ($400/site) | Multi(×33)+F Trace Element analysis ($350/site) |
|---|---|---|---|---|---|
| Intensive pasture – dairy | 36 | $15,000 | $9,000 | $14,400 | $12,600 |
| Intensive pasture – dry stock | 31 | $12,500 | $7,750 | $12,400 | $10,850 |
| Intensive pasture/arable | 20* | $10,000 | $5,000 | $8,000 | $7,000 |
| Extensive pasture – dry stock | 23 | $11,500 | $5,750 | $9,200 | $8,050 |
| Horticulture | 10 | $5,000 | $2,500 | $4,000 | $3,500 |
| Forestry – exotic | 20 | $10,000 | $5,000 | $8,000 | $7,000 |
| Indigenous forest | 20 | $10,000 | $5,000 | $8,000 | $7,000 |
| Indigenous grassland | 20 | $10,000 | $5,000 | $8,000 | $7,000 |
| Total | 180 | $84,000 | $45,000 | $72,000 | $63,000 |

*Suggested that half of arable sites are selected from permanent cropping and half from pasture/crop rotation land uses

## 6.2 Scenario II: Minimal Design

### Soil Quality and Trace Elements

The minimal design for SQ and trace element monitoring uses a reduced land use/soil design of pasture and indigenous forest. However, the same number of pasture sites has been used as pasture land use is of greatest concern to ES. For trace element analysis the environmental suite (As, Cd, Cr, Cu, Pb, Ni, and Zn) plus fluoride has been used to calculate laboratory costs (Table 3).

**Table 3** Scenario II costing based on number of sites selected. Cost of establishment and first sampling (phase 1) separated from re-sampling (phase 2). Laboratory analysis costs are the same for both phases

| Land use class | Sites required | Establishment and sampling cost ($500/site) at 2 sites/day | Re-sampling cost ($250/site) at 4sites/day | Lab analysis for 7 SQ indicators ($400/site) | Environmental(×7)+F Trace Element analysis ($180/site) |
|---|---|---|---|---|---|
| Intensive pasture – dairy | 30 | $12,000 | $7,500 | $12,000 | $5,400 |
| Intensive pasture – dry stock | 30 | $12,000 | $7,500 | $12,000 | $5,400 |
| Extensive pasture – dry stock | 20 | $10,000 | $5,000 | $8,000 | $3,600 |
| Indigenous forest | 10 | $5,000 | $2,500 | $4,000 | $1,800 |
| Total | 90 | $39,000 | $22,500 | $36,000 | $16,200 |

### Soil Stability

The minimal design for SS uses a 2 × 2-km grid across Southland excluding Fiordland, while eastern Fiordland would have a 3 × 3-km grid. Western Fiordland would not be assessed. Costs in this scenario are based on 10-yearly assessment of approximately 5000 data points.

## 6.3 Summary Costs

Table 4 provides a comparison of costs between scenarios I and II. Soil stability is monitored 5 yearly in scenario I, and 10 yearly (not recommended) in scenario II; all other costs are based on a 5-yearly monitoring cycle (costs may be cut if forestry and indigenous sites are sampled less frequently as suggested). Annual costs for the first five years, i.e. phase 1, would be approximately 20% higher. Cost estimates are for SoE monitoring; no costs have been calculated for reporting.

**Table 4** Comparison of two price scenarios

| Scenario | SQ set up phase | SQ re-sampling | SQ lab analysis | TE analysis | SS | Total annual costs phase 2 |
|---|---|---|---|---|---|---|
| I | $79,000 | $42,500 | $68,000 | $59,500 | $15,000 | $37,000 |
| II | $44,000 | $25,000 | $40,000 | $18,000 | $10,000 | $17,600 |

## 7 Recommendations

- It is recommended that ES consider the review of SQ in this document and assess the methods outlined before deciding on a SQ and SS design for Southland.
- It is recommended that ES review both monitoring scenarios and choose the most appropriate design for the budget they have allocated. This may involve taking pieces out of both scenarios to tailor the most cost-effective programme for the region.
- Environment Southland should continue monitoring existing SQ sites; however, all future sampling (new and existing sites) should be done at the same time of the year when soil conditions are optimum for collecting intact cores.
- Use of existing data from previously sampled and/or described sites such as from LUCAS and NSD should be considered in SQ site selection. Landcare Research can provide relevant data on request.
- Soil stability should be monitored on a regular basis at an intensity that allows robust comparisons to be made temporally and on all major (> 1% by area) land uses.
- Where possible, but keeping in mind the integrity of this programme, ES should align SQ and SS monitoring with other SoE monitoring in Southland, particularly ground-water monitoring.

## 8 Acknowledgements

We would like to acknowledge advice and support from:

Les Basher – Landcare Research

Reece Hill – Waikato Regional Council

Mathew Taylor – Waikato Regional Council

John Drury – Greater Wellington Regional Council

George Ledgard – Environment Southland

## 9 References

Burton AS 2001. Soil intactness monitoring programme for the Tasman District. Richmond, Tasman District Council.

Burton AS, Taylor A, Hicks DL 2009. Assessing soil stability. In: Land and soil monitoring: a guide for SoE and regional council reporting. Hamilton, Land Monitoring Forum. Pp. 89–116.

Hewitt AE 2010. New Zealand soil classification. 3rd edn Lincoln, Manaaki Whenua Press. 136 p.

Hill RB, Sparling GP 2009. Soil quality monitoring. In: Land and soil monitoring: a guide for SoE and regional council reporting. Hamilton, Land Monitoring Forum. Pp. 27–88.

Land Monitoring Forum 2009. Land and soil monitoring: A guide for SoE and regional council reporting, Wellington, Ministry for the Environment.

Lilburn LR, Webb TH, Hewitt AE, Lynn IH, de Pauw B 2011 S-map database manual v1.2. Landcare Research Contract Report LC478 for Ministry of Science and Innovation. 55 p.

Milne D, Claydon B, Singleton PL, Wilson AD 1995. Soil description handbook (rev. edn). Lincoln, Manaaki Whenua Press.

Resource Management Act 1991. Wellington, New Zealand Government Printer.

Schipper LA, Parfitt RL, Ross C, Baisden WT, Claydon JJ, Fraser S 2010. Gains and losses in C and N stocks of New Zealand pasture soils depend on land use. Agriculture, Ecosystems and Environment 139(4): 611–617.

Sparling GP, Schipper LA 2000. Performance of soil condition indicators across taxonomic groups and land uses. Soil Science Society of America Journal 64: 300–311.

Sparling GP, Schipper LA 2002. Soil quality at a national scale in New Zealand. Journal of Environmental Quality 31: 1848–1857.

Sparling G, Lilburne L, Vojvodic-Vucovic M 2003. Provisional targets for soil quality indicators in New Zealand. Lincoln, Landcare Research.

Sparling GP, Schipper LA, Bettjeeman W, Hill R 2004. Soil quality monitoring in New Zealand: practical lessons from a six-year trial. Agriculture, Ecosystems and Environment 104: 523–534.

Stevenson B, McNeil S, Hewitt A 2012. Utilising the soil quality dataset: multivariate and spatial analysis of soil quality data. Landcare Research Report LC 1060. 25 p.

Taylor MD, Kim ND, Hill RB, Chapman R 2010. A review of soil quality indicators and five key issues after 12 yr soil quality monitoring in the Waikato region. Soil Use and Management 26: 212–224.

Thompson AB, Hicks DL 2009. Changes in soil stability in the Waikato Region from 2002 to 2007. Environment Waikato Technical Report 2009/30

# Appendix 1 – Potential SQ Sites from NSD and LUCAS

**Table 5** Sites for further consideration. Site details and co-ordinates available on request

| Type | Code | Vegetation | Soil code |
|---|---|---|---|
| LUCAS | R170 | Nat.For | HumTemp_POD |
| LUCAS | P168 | Nat.For | HumTemp_HAC |
| LUCAS | N170 | Nat.For | HumTemp_AQU |
| LUCAS | M171 | Nat.For | HumTemp_ORG |
| LUCAS | N168 | Nat.For | HumTemp_AQU |
| LUCAS | O167 | Nat.For | HumTemp_HAC |
| LUCAS | N166 | Nat.For | HumTemp_HAC |
| LUCAS | N165 | Nat.For | HumTemp_LAC |
| LUCAS | S163 | Nat.For | HumTemp_HAC |
| LUCAS | U159 | Nat.For | HumTemp_HAC |
| LUCAS | V161 | Nat.For | HumTemp_HAC |
| LUCAS | AA160 | Grass.Low | HumBor_HAC |
| LUCAS | AC160 | Nat.For | HumTemp_POD |
| LUCAS | U159 | Nat.For | HumTemp_HAC |
| LUCAS | R159 | Nat.For | HumTemp_HAC |
| LUCAS | R158 | Nat.For | HumTemp_POD |
| LUCAS | Q156 | Nat.For | HumTemp_HAC |
| NSD | 8476 | Podocarp/broadleaf | GAT |
| NSD | 7696 | Podocarp/broadleaf | POD |
| NSD | 9576 | Podocarp/broadleaf | POD |
| NSD | 9215 | Pasture | BFT |
| NSD | 10133 | Pasture | BUT |
| NSD/SLMACC | 9298 | Pasture | PPX |
| NSD/SLMACC | 9116 | Pasture | PXM |
| NSD/SLMACC | 10050 | Pasture | PXM |
| NSD | 10052 | Pasture | RFM |
| NSD | 10051 | Pasture | RFM |
| NSD/SLMACC | 8342 | Pasture | PPJ |
| NSD | 10048 | Pasture | PLT |
| NSD/SLMACC | 10047 | Pasture | GOE |
| NSD | 10135 | Pasture | BMA |
| NSD | 10136 | Pasture | BOT |
| NSD | 10138 | Pasture | BFL |
| NSD | 9574 | Pasture | BLX |
| NSD | 10139 | Pasture | BOA |
| NSD | 9876 | Pasture | EOJ |

## Appendix 2 – Soil quality results 2011/2012

Data from ten pasture SQ sites (6 dry stock; 4 dairy) were analyzed and is presented below. Table 6 shows values for each indicator measured with values outside target ranges highlighted (blue above target, orange below target)

**Table 6** Summary data for dairy and dry stock monitoring sites

| Site Code | Soil | Land Use | pH | Total C T/ha | Total N T/ha | AMN μg/cm$^3$ | Olsen P μg/cm$^3$ | Bulk Density T/m$^3$ | Macropores (–10kPa) %v/v |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Brown | Dairy | 6.4 | 43.8 | 4.75 | 147 | 37 | 1.25 | 10.3 |
| 2 | Brown | Dairy | 5.9 | 51.5 | 4.21 | 222 | 28 | 1.17 | **8.7** |
| 3 | Gley | Drystock | 6.2 | 43.7 | 4.37 | 238 | 25 | 1.04 | **7.3** |
| 4 | Brown | Drystock | 5.7 | 88.9 | 5.08 | 183 | 22 | 0.91 | **9.7** |
| 5 | Gley | Drystock | 6.1 | 106.2 | 4.86 | 169 | 18 | 0.64 | **8.7** |
| 6 | Pallic | Drystock | 5.6 | 74.0 | 5.13 | **285** | 19 | 0.99 | **6.7** |
| 7 | Brown | Dairy | 5.9 | 118.0 | 6.10 | 168 | 15 | 0.98 | **6.0** |
| 8 | Brown | Drystock | 6.2 | 63.5 | 6.06 | **386** | 24 | 0.98 | **5.7** |
| 9 | Pallic | Drystock | 5.9 | 40.8 | 4.32 | 144 | **14** | 1.20 | **9.0** |
| 10 | Brown | Dairy | 6.2 | 56.8 | 5.78 | **293** | 17 | 0.98 | **8.3** |

Site codes are given in Table 7.

**Table 7** Site description provided by ES and site code applied by Landcare Research

| Site | Code |
|---|---|
| Ferndale, Mataura-Clinton Highway | 1 |
| Heenans Corner, Hundred Line Road | 2 |
| Islabank, Argyle Otahuti Road | 3 |
| Lawson Road , Lawson Road | 4 |
| Lawson Road South, Lawson Road | 5 |
| Makarewa, Flora Road | 6 |
| South coast, Haldine Curio Bay Road | 7 |
| Waiarikiki, Waiarikiki Road | 8 |
| Willow Bank, Cunningham Road | 9 |
| Woodlands, Garvey Road | 10 |

Only one site had all indicators within target range, while the rest had one or two indicators outside target ranges (Figure 5).

Figure 6 shows that macroporosity was the indicator most likely to be outside the target range.

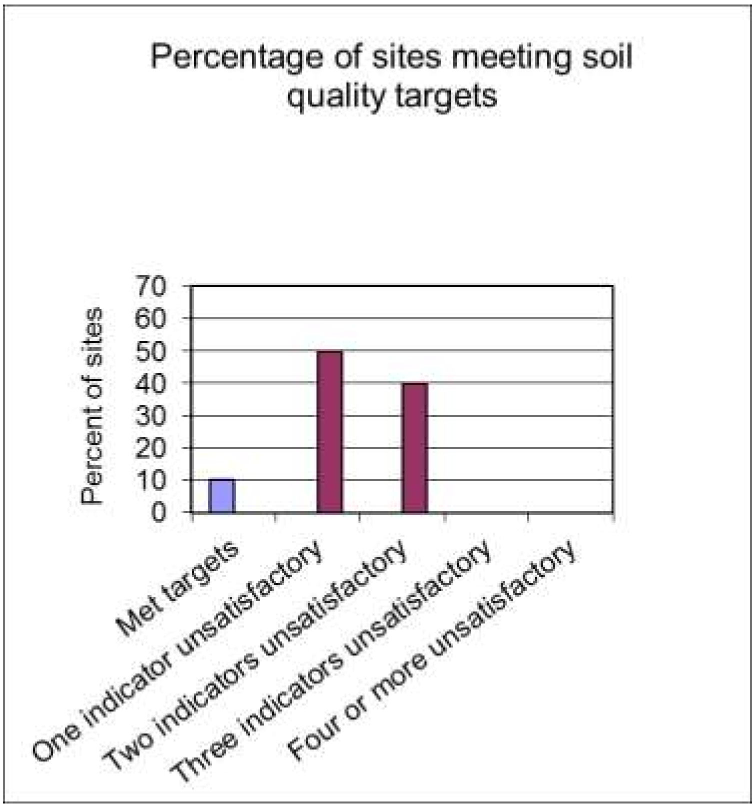


**Figure 5** Percentage of sites meeting targets.

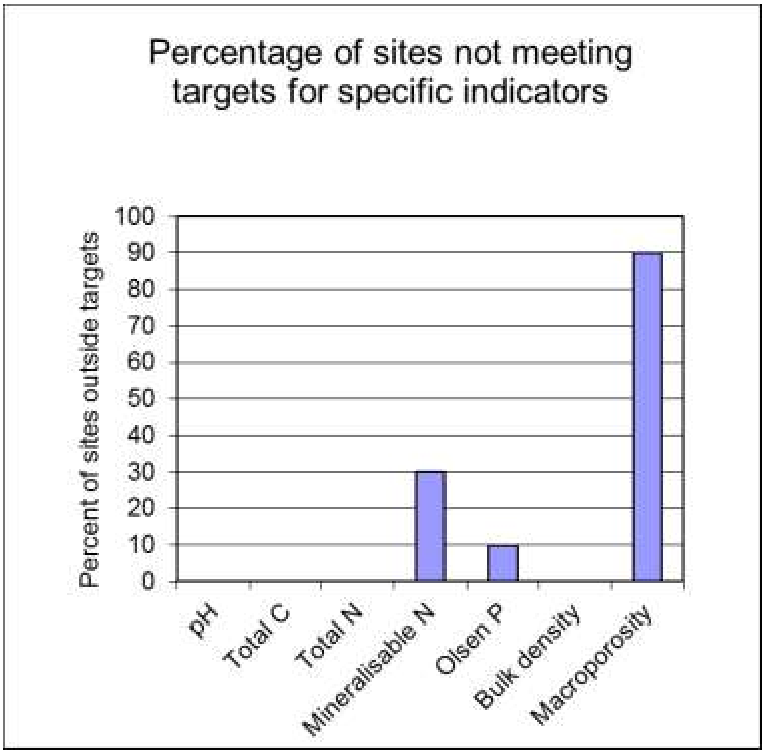


**Figure 6** Percentage of sites not meeting targets for specific indicators.