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National Soil Condition Monitoring for soil pH and soil carbon

Objectives, Design, Protocols, Governance and Reporting

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CARING FOR OUR COUNTRY

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Description: Monitoring Australia's soils – a montage of images from project field trials.
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EXECUTIVE SUMMARY

This work was commissioned by the Australian Government through its Caring for our Country initiative. Caring for our Country is investing in the uptake of land management practices by farmers which will slow and reverse rates of soil acidification and increase soil organic matter storage to improve the condition of Australia's soil resource. Resource condition monitoring is needed to establish whether these investments are helping to improve soil condition. Changes in soil pH and soil carbon can occur quite slowly; a long term program which monitors sites about every 5 years is needed for these changes to be detected. In addition to setting a baseline and reporting on resource condition, a monitoring program will also improve the information needed to identify where further land degradation is most likely to occur, and where future investments in improving land management practices will achieve the best returns.

Protocols for Implementation and Operation

This report presents: operating procedures and guidelines for National Soil Condition Monitoring, testing of the methodology, a proposed Program governance structure, selected priority monitoring units, a statistical model and Program cost estimates. Trials were conducted within each Australian jurisdiction to test the protocols and advise on required approaches. Some operational issues (such as spatial identification of monitoring units, methods for bulk density sampling and explicit procedures for soil analysis and data collation) will require more consideration during program implementation.

Rationale for a National Soil Condition Monitoring Program

A National Soil Condition Monitoring Program is critical to understanding how Australia's soil resources are being affected by agricultural management practices and climate change.

Soil is a fundamental natural resource and its condition and use has a major impact on the economy and human health. Soil condition information is required to support critical decisions related to local, regional, national and international issues such as food security, environmental sustainability, carbon and greenhouse gas accounting, water availability and use.

Linkages with previous work and other monitoring programs

This document follows previous work conducted to determine the need and focus of a National Soil Condition Monitoring Program (McKenzie *et al.* 2002, McKenzie and Dixon 2007, Dixon 2007, and Baldock *et al.* 2010).

The current Soil Carbon Research Program (SCaRP) managed by CSIRO has a key output to quantify the amount of carbon stored in soils under different agricultural practices on a regional basis across Australia. The fundamental difference between SCaRP and the National Soil Condition Monitoring Program lies in the temporal aspect of the sample collection. SCaRP will provide an assessment of current soil carbon status and what the integrative effect of land use history has been on soil carbon levels. The National Soil Condition Monitoring Program will initiate and monitor change through time using repeated sampling on a 5 year return basis and thus establish the ongoing impact of land use and management practices.

State monitoring programs are being conducted in Tasmania (*Soil Condition Evaluation and Monitoring - SCEAM)*, New South Wales (*Monitoring, Evaluation and Reporting Program - MER*) and Western Australia (*Soil monitoring network for Western Australian wheatbelt*).

These programs have been established to monitor soil properties of interest at selected locations to assist with guiding State objectives.

In preparing this document, relevant experiences from other national and state monitoring programs were integrated. There are similarities in approach particularly with collection methods of soil samples, analysis, data collection and soil variables measured. Approaches are complementary, and data can be shared to provide larger improved data sets for interpretation.

Objectives

The National Soil Condition Monitoring Program is designed around three questions:

1) What are the magnitudes and directions of soil organic carbon and soil pH changes for representative soil and land use combinations?

2) What are the levels of certainty (statistical confidence) associated with the measured soil carbon and pH changes?

3) What can be inferred about the changes in soil carbon and pH across different environments and the influence of land use and/or land management? Is Australia's soil resource degrading, maintaining or improving under current agricultural systems?

Survey Design

A National Soil Condition Monitoring Program is developed to apply across Australia to provide consistent information for future assessment and reporting.

The approach is to identify how the mean soil organic carbon percentage and the mean pH of a sampled population changes over a period of at least 20 years.

To detect long term trends, a large sampling effort is required to separate relatively small temporal change from often-larger spatial variation. Repeat measurements will be conducted at the same site locations over time to enable analysis of the difference at individual sites and infer trends for selected significant landscapes across Australia.

Monitoring Units and Sites

Reporting will be by specified Monitoring Units, defined by relatively uniform soil characteristics and land use.

It is not possible to monitor every soil and land use combination and prioritisation has targeted agricultural areas, vulnerable soils and important land uses. Monitoring is therefore directed towards important exemplar landscapes and land uses where change in soil organic carbon or soil pH is likely to occur.

Each Jurisdiction has identified two Monitoring Units, one that is a priority for soil organic carbon and the other for soil pH. The Monitoring Units selected and their locations are shown in Figure A.

A Monitoring Site is a single expression of a Monitoring Unit and is where the soil samples for laboratory analysis are collected. Permanent Monitoring Sites will be established as 25 by 25 metre squares that can be accurately relocated to allow repeat sampling. For each Monitoring Unit it is estimated that at least 100 Monitoring Sites will be established.

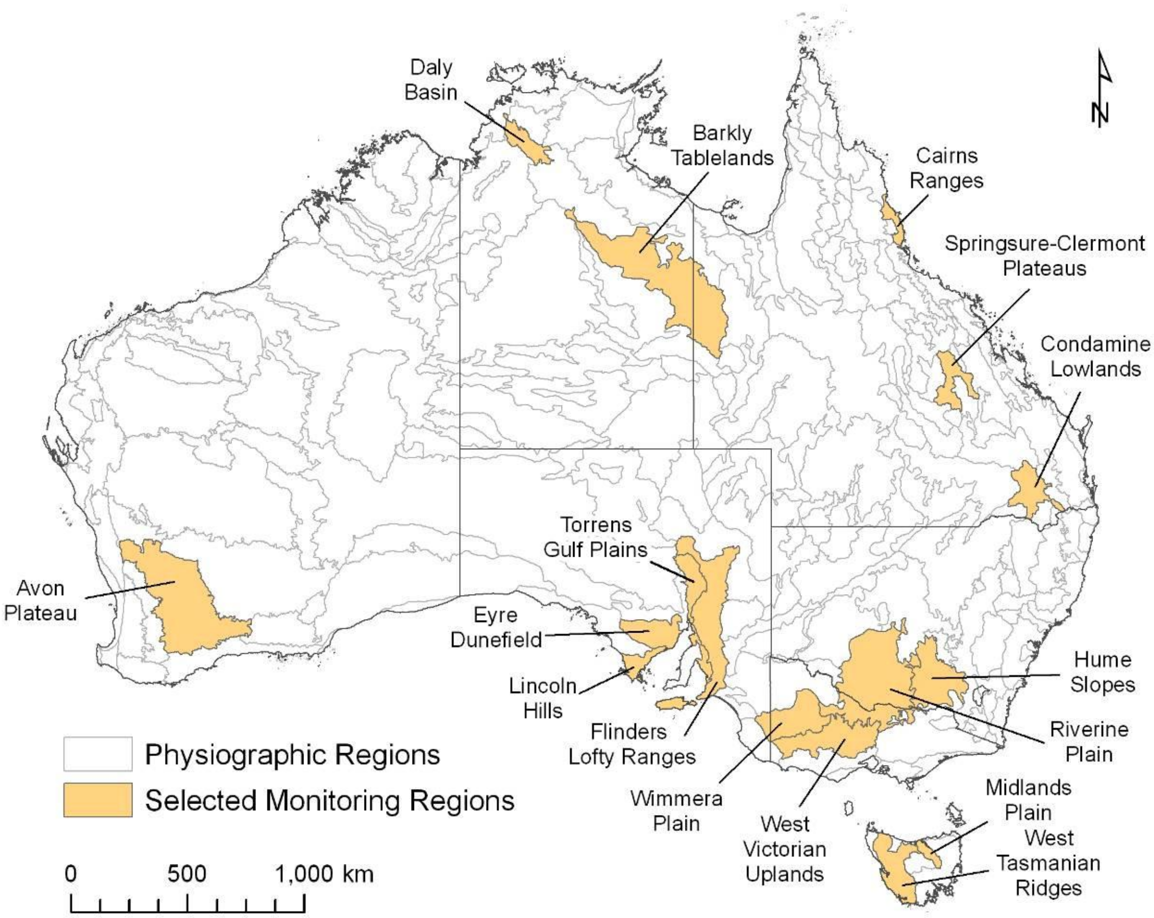


Figure A. Location of the 14 Monitoring Units prioritised for initial sampling.

Program Governance

A National Soil Condition Monitoring Program will need to operate for decades to obtain results with regard to long-term trends in soil condition. The Program is designed to be as rigorous as possible to meet current needs and flexible to accommodate future monitoring requirements (such as other variables or more regular sampling events).

Agreement between all jurisdictions and Australian Government agencies needs to be in place prior to a Program starting, to address issues such as privacy and confidentiality, intellectual property and data ownership, and cost sharing arrangements.

Cost Estimate and Schedule

The schedule proposed allows for Monitoring Sites to be established in a staged approach over 5 years and revisiting of sites thereafter on the same rotation. A staged approach offers a number of benefits: as data becomes available each year the Program can be adapted and improved; provides continuity of work for skilled people on the project; provides measurements for each year; smooths out the flow of funds required; maintains continuity and visibility of the project.

Cost estimates are presented in Table A. Assumptions for calculating the cost estimate include: each jurisdiction establishes 2 Monitoring Units with 100 Monitoring Sites in each Monitoring Unit, 5 years to establish and 15 years of Monitoring (total of 20 years); each jurisdiction would have 1.5 full time equivalent staff for first 5 years and 1 full time equivalent staff thereafter; the National Team would have 1 full time equivalent coordinator, and 2.5 full time equivalents technical support staff to provide contractual, technical and data management support.

The Program could be expanded if more funds become available for additional Monitoring Units to be established and/or additional soil variables to be included. It is also likely that the value of the Program would continue to grow as additional questions are asked about the sustainability of Australia's soil resource, agricultural systems and environment. It would therefore be beneficial if the Program is established in an enduring organisation and that necessary funding is established as a permanent budget item.

Table A. The table presents a summary of the cost estimate to operate the National Soil Condition Monitoring Program (dollar figures are for 2011 and not adjusted for subsequent years).

	Years 1 to 5 Establishment of Monitoring Sites	Years 6 to 20 On-going data collection of Monitoring Sites
Oversight Committee	100,000	75,000
National Team	1,000,000	650,000
Jurisdiction teams (for 7 teams)	2,520,000	1,820,000
Central Soil Analytical Laboratory	1,550,976	775,509
SUB TOTAL for one year	$5,170,976	$3,320,509
TOTAL for all years	For 5 years - $25,854,880	For 15 years - $49,807,635

The **gross value of Australian farm production** (at farm-gate) totals **$41.8 billion-a-year**. (*Farm Facts 2011*, National Farmers Federation).

The estimated $5 million per year **investment required for** this component of **soil condition monitoring** is **less than 0.01%** of the annual production value, which is **a small price to pay for sustainability** monitoring.

These are significant resource requirements, but can be justified within the value of industry and agricultural productivity which is dependent on a healthy soil resource base.

Initial Soil Sample Results

As part of the trial implementation of the National Soil Condition Monitoring Program, at least two sites have been established in each of two priority Monitoring Units identified in each jurisdiction. The initial results have been used to develop and test methods, results are presented in Appendix A.

1. INTRODUCTION

This document presents operational specifications to establish a robust national program for long term monitoring of soil condition that will focus on two soil variables: soil carbon and soil pH.

The project is designed to support the sustainable farming outcomes and targets for Caring for our Country, that aim to improve land management practices expressed in part by a build up of soil carbon and reduction of the risk of soil acidification and to provide for long term reporting of soil condition.

Previous work conducted over recent years has established the need, rationale and general approach required for an Australian National Soil Condition Monitoring Program. This information was presented in four reports:

- Monitoring Soil Change – Principles and practices for Australian conditions (McKenzie, Henderson and McDonald, 2002).
- Monitoring Soil condition Across Australia – Recommendations from the Expert Panels (McKenzie and Dixon, 2007).
- Soil Condition Monitoring Trial: Summary Report (Dixon, 2007)
- Building a Foundation for Soil Condition Assessment (Baldock, Grundy, Griffin, Webb, Wong and Broos, 2010).

This document follows-on as a companion report to those listed above and **focuses on the establishment of operational protocols that allows a National Soil Condition Monitoring Program to be implemented**. This is a technical document of standard operating procedures, guidelines, and methods to follow enabling a consistent standardised approach to be conducted throughout the country. For background and information on the program design and rationale the earlier companion reports listed above should be referred to.

The protocols presented in this document have been prepared by staff from CSIRO Land and Water and representatives from State and Territory agencies. It draws on the knowledge gained from a series of jurisdictional trials (Appendix B) and documentation prepared from other related soil monitoring programs by these agencies.

1.1. Linkages with other Soil Monitoring Programs

Related soil assessment and monitoring programs currently being conducted in Australia include the following.

National Program

The Soil Carbon Research Program (SCaRP) is managed by CSIRO and the main output is the quantification of the amount of carbon stored in soils under different agricultural practices on a regional basis across Australia. The fundamental difference between SCaRP and the National Soil Condition Monitoring Program lies in the temporal aspect of the sample collection. SCaRP will provide an assessment of the relative soil carbon status and what the integrative effect of land use history has been on soil carbon levels. The National Soil Condition Monitoring Program will use repeated sampling of the key land uses on a 5 to 10 year cycle to determine whether key soil properties are changing.

State Programs

State programs are being conducted in Tasmania (*Soil Condition Evaluation and Monitoring - SCEAM)*, New South Wales (*Monitoring, Evaluation and Reporting Program - MER*) and Western Australia (*Soil monitoring network for Western Australian wheatbelt*). These programs have been established to measure soil properties of interest at selected locations to provide monitoring data to assist with guiding State objectives. A brief description for each State program follows:

Soil Condition Evaluation and Monitoring (SCEAM) – This is a project conducted by Tasmanian Department of Primary Industries and Water in three Natural Resource Management Regions. Key output is the quantification of soil condition with measurements of soil physical and chemical properties, with repeat sampling of sites every 5 years. This project is similar to the National Soil Condition Monitoring Program but with some site and methodology differences.

Monitoring, Evaluation and Reporting Program (MER) – This project is conducted by the Department of Environment and Climate Change in New South Wales across all Catchment Management Areas. Key outputs are a set of baseline measurements at sites that form a state-wide network that will be revisited to measure long-term changes in soil condition. This project is similar to the National Soil Condition Monitoring Program but with some site selection differences.

Soil monitoring network for Western Australian wheatbelt – This project is conducted by the Department of Agriculture and Food, Western Australia at selected locations throughout the wheatbelt agriculture area. Key outputs are a set of baseline measurements of soil pH to form a network across cropping and pasture land use on a range of soil types and climate regions. This project is similar to the National Soil condition Monitoring Program but with a focus on only soil pH, although soil organic carbon could also be measured on the collected samples, and there are some site selection differences.

This document includes an integration of relevant experiences from national and state monitoring programs. These programs are built on McKenzie *et al.* (2002b) and there are similarities in approach, particularly with soil sample collection, analysis, data collection and the soil variables measured. Approaches are complementary and data can be shared to provide an opportunity for more robust interpretations.

These programs differ in purpose and have some differences in execution especially monitoring site selection. The National Soil Condition Monitoring Program is designed to determine the long-term trends with a high degree of statistical certainty for the findings will guide strategic national investment decisions in land use and management and to provide for long term reporting of soil condition. Therefore the site selection process minimises subjectivity to ensure representativeness of the Monitoring Units.

1.2. Terminology

Land use refers to the purpose to which the land is committed. Land use is determined in consultation with the land manager and allocated to the land use categories as defined by the Australian Collaborative Land Use Mapping Program (ACLUMP) http://adl.brs.gov.au/mapserv/landuse/index.cfm?fa=classification.class&tab=class.

Land management practice is the approach taken to achieve a land use outcome - the 'how' of land use (e.g. cultivation practices, such as minimum tillage and direct drilling). Some land management practices, such as stubble disposal practices and tillage rotation systems, may be discriminated by characteristic land cover patterns and be linked to particular soil condition issues.

Monitoring Region is the primary geographical stratification, which together constitute the extent of continental Australia and is monitored for national reporting. The Monitoring Regions are based on physiographic regions (Pain and Gregory, 2011 in prep) which have a characteristic landform pattern and geomorphology. Climate parameters tend to have a narrow range, partly through the limited size of these regions and partly because climate has been a major influence on geomorphology. The chosen Monitoring Regions represent a cross-section of the major Australian agricultural areas where land management is likely to have a significant influence on soil condition.

Monitoring Unit is the primary land area of monitoring, where soil characteristics, climate and land use are relatively uniform and it is expected that changes in soil condition indicators would be of a similar magnitude for similar land management actions. The Monitoring Units chosen will constitute a specific subset of the land use and soil type in a Monitoring Region.

Monitoring Site is a single geographic expression of a Monitoring Unit within a Monitoring Region (that is a single soil type by land use/management practice combination). Monitoring Sites represent the base unit in the National Monitoring Program. Many Monitoring Sites would be established within each selected Monitoring Unit. The Monitoring Site is a 25 m by 25 m square covering a total area of 625 m^2 and represents a standardised “soil individual” (McKenzie *et al*., 2002, McKenzie *et al*., 2008).

1.3. Structure of this document

This document provides the operational specifications to establish a national site network to monitor soil organic carbon and soil pH. The document is structured as follows:

Section 1: Introduction

Provides background history to the Program and linkages with other work

Section 2: Program Objectives

- lists the questions being asked and identifies the soil variables to be monitored

Section 3: Survey Design

- discusses the rationale, approach, statistical design, and establishing the network.

Section 4: Data Collection

- provides standard operating procedures, guidelines, and laboratory methods for data collection

Section 5: Reporting, Data Management and Sample Archiving

- describes the reporting format, long term handling of data and soil samples

Section 6: Quality Assurance and Quality Control

- a checklist to ensure valid data and interpretation

Section 7: Program Governance

- presents the Program structure and responsibilities

Section 8: Resource Requirements and Schedule

- provides a cost estimate of resource requirements to establish the monitoring network and maintain a long term program

Appendix 1 to 6:

- provides details for the analytical methodologies, template forms for Landowner questionaries and summary report structure for Monitoring Units

Appendix A: Candidate Monitoring Regions, Monitoring Units, and Data

Identifies the selected Monitoring Units, and results from sampling sites

Appendix B: Summary reports from jurisdictional trial implementation projects

2. OBJECTIVES

2.1. Questions to be answered by the national program

The National Soil Condition Monitoring Program is designed around three questions:

1) What are the magnitudes and direction of soil carbon and soil pH changes for representative soil and land use combinations?

2) What are the levels of certainty (statistical confidence) associated with the measured soil carbon and pH changes?

3) What understanding can be inferred about the changes in soil carbon and pH across different environments and the influence of land uses and/or land management practices?

The Program is designed to address the first two questions in a cost effective manner.

While not the focus of the program, the third question opens up the option to consider why any change has occurred.

2.2. Soil variables to be monitored

There are many properties which influence soil condition. The National Land and Water Resources Audit identified four key indicators and the National Soil Condition Monitoring Program focuses on two of these to be measured and monitored, they are:

- Soil organic carbon.
- Soil pH.

The National Committee on Soil and Terrain selected these variables as they exert some level of control or influence over multiple soil properties and will provide the greatest return on investment (McKenzie and Dixon, 2007; Dixon 2007). The other two indicators for wind and water erosion are considered in other programs (e.g. Leys *et al.* 2009 and Bui *et al.* 2010 for soil erosion).

Baldock *et al.* (2010) in reporting of the selection of these variables noted that - “Increasing the quantity of soil organic carbon will provide positive responses in a range of soil biological, chemical and physical properties with the additional benefit of reducing the concentration of carbon dioxide in the atmosphere. Soil acidification is a consequence of the removal of products associated with agricultural production or leaching. Increasing soil acidity adversely affects numerous soil properties and can result in irreparable damage to the soil resource if left unchecked. Ultimately, losses of soil carbon and acidification will restrict future productivity and land use options.”

This document focuses on requirements for monitoring of soil organic carbon and soil pH. The measurement and monitoring must be conducted according to the protocols and guidelines provided in this report to maintain standards and maximise the reliability of results.

Most State and Territory agencies have site based monitoring programs that may serve a dual purpose with the National Soil Condition Monitoring Program and they may include monitoring of some additional soil and environmental variables. This complementary work is encouraged, but must not compromise the reliability of the data collected for the National Soil Condition Monitoring Program.

3. SURVEY DESIGN

This section outlines the survey design approach and identifies the spatial units (Monitoring Regions, Monitoring Units and candidate Monitoring Sites) that will be distributed throughout Australia to form a network to be used for the National Soil Condition Monitoring Program. The questions asked of the National Program were presented in Section 2.1.

3.1. Rationale and approach

The rationale and approach for the survey design is discussed in the report 'Monitoring Soil Change – Principles and practices for Australian conditions' (McKenzie *et al.* 2002), for selection of soil properties to monitor in McKenzie and Dixon, 2007, and for the spatial elements in the report 'Building a Foundation for Soil Condition Assessment' (Baldock *et al.* 2010).

Key points to note from these reports include:

- The National Soil Condition Monitoring Program is developed to apply across all of Australia to provide a consistent dataset of information for assessment and reporting.
- It is not possible to monitor the condition of Australian soil as a whole because it would be a massive task and probable resources available are not likely to match the effort required.
- As the purpose is to obtain an indication on the impacts of management of land, the focus is on:
    - agricultural areas - because the focus is to determine what change is occurring in these managed areas.
    - vulnerable soils – because these are the areas where early change is likely to be detected, and
    - important land uses – because the results need to be applicable to those areas that are extensive and/or where significant investment is made.
- Because of the wide variation in soil pH and organic carbon across Australia partitioning the areas monitored into separate soil populations with a narrow range of parent material and climate influences will more readily detect change.
- To minimise the effect of the spatial variation in these soil properties, the same locations are sampled over time.
- Changes in soil properties can be positive due to investment and improved land management, or negative due to degradation and inappropriate land management, or neutral due to maintenance actions. The time frame for the National Soil Condition Monitoring Program is to identify the long-term trend. The Monitoring Program will not comprehensively examine all Australian landscapes, but will identify important exemplary landscapes and land uses having the potential to induce changes in soil organic carbon and soil pH. With this in place, additional and/or more intensive future monitoring schemes could fit within this National Program (Baldock *et al.*, 2010).
- Monitoring is further focused on areas where early change in the soil properties is likely to occur. This attempts to be cost effective in allocating resources (McKenzie *et al.*, 2002) and it ensures that monitoring provides an early indication of the trend which may be a warning if there is degradation or support if there has been improvement or maintenance of the soil condition.
- The monitored population is a number of Monitoring Units distributed throughout Australia, each geographically constrained by Monitoring Regions. These units are

combinations of soil type and land use (for example, Brown Chromosols and cereal cropping). With regard to soil type, the emphasis need not be on a classification unit (such as Chromosols) but on a consistent set of soil attributes or functional qualities that may cut across traditional classification units. It ma be necessary to define the range of soil properties acceptable within a monitoring unit. For monitoring of other variables the appropriateness of these units and sites should be considered (Baldock *et al.*, 2010).

- A large sampling effort is often required to detect the relatively small changes over time against the often-large spatial fluctuations that occur at a range of scales (McKenzie *et al.*, 2002). Therefore many sites and long return times are required.
- The processes causing changes in soil pH and soil organic carbon are generally slow, and high spatial and seasonal variability can make detection of trends difficult. Change is likely to be undetectable in less than five years even in the most severe cases of degradation but can be more consistently determined over a ten year period (McKenzie and Dixon, 2007). This long term process requires an equally long-term monitoring program. However, changes in soil pH and soil organic carbon can be rapid depending on the management and/or environmental factors and there may a need to monitor across a shorter timeframe possibly corresponding with a specific funding investment cycles or a requirement to capture the short term variation to better understand the long term trend.
- The program is about detecting change rather than determining a reliable estimate of a population mean, it is efficient to repeat measurements over time at the *same* sites and to then analyse differences between individual sites over time. The alternative of comparing the mean value of a soil property across all sites at time zero with the mean for all sites at a later time is an inefficient and ineffective method for detecting change (McKenzie *et al.*, 2002). This is demonstrated in Figure 3-1, where a reproduction of Figure 11 from the McKenzie *et al.* (2002b) report explains this point.
- Repeat measurements over time are to be made at the same sites therefore the sites need to be accurately relocatable and of sufficient size to be representative and minimise heterogeneity of the soil. The site is recommended to be 25 m by 25 m in size (McKenzie *et al.* 2002; Baldock *et al.* 2010) and is consistent with the established ‘soil individual’ concept (McKenzie *et al.* 2002a and McKenzie *et al.* 2008).
- If there is a shift in land use and that is relatively consistent across the Monitoring Unit (for example, because of climate change cereal cropping to permanent pasture) then the sites are maintained and the change in land use is noted.
- The strength of this approach is to detect change (magnitude and direction) in the soil property with time and specify the confidence of that change; the weakness is that it has less power to determine if land use and/or land management practice and/or environmental factors influenced the change.

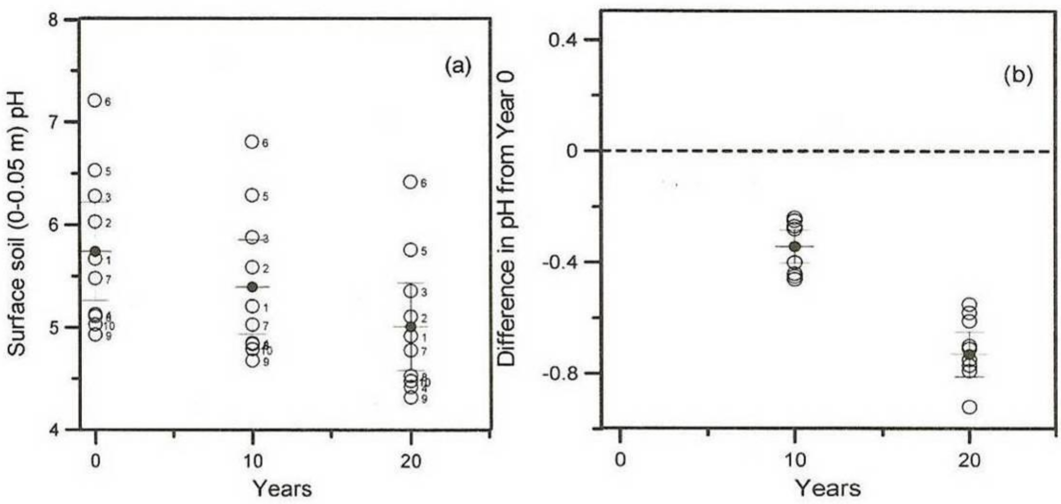


Figure 11: Hypothetical example of pH change over 20 years for 10 sites (site numbers are shown in (a)). In (a) the average pH for each time interval is calculated and presented as a mean (●) with 95% confidence intervals – the intervals overlap for the three times so no statistical significant change is detected. In (b) the information for each site is retained in the analysis and the *difference* in pH for each site from Year 0 is plotted. The resulting confidence intervals are much smaller and a strongly significant statistical difference is detected. The analysis in (b) is not possible if different sites are used in each period of sampling.

Figure 3-1. Demonstration of the analysis of differences between individual sites over time. A reproduction of Figure 11 from McKenzie *et al.*, 2002.

3.2. Statistical model

A model based approach to monitoring of soil properties (soil organic carbon content and soil pH) over time requires a statistical model for the observed measurements at each site and at each time point. At a minimum, the model should include a time effect to quantify linear trend over time as well as allow for the fact that measurements at the same site are correlated. This statistical model will indicate how the data will be analysed, which will also help decided how many sites should be chosen to be able to reliably detect change over the life of the monitoring scheme.

The statistical model follows the approach presented on page 85 of McKenzie *et al.* (2002b) where the algebraic form for the model is

- $Y_{i,j,t} = \mu + \beta\, x_t + S_i + \varepsilon_{i,j,t}$ for sites i, measurement j at time point t.

The term μ in this model denotes the baseline mean for the region at the start of the monitoring (time $x_t = 0$, t=1). The term x_t is the time elapse between time point t and the start of the monitoring scheme in years, so $x_1 = 0$ years, $x_2 = 5$ years etc. The term β is the change in response for a one year period. The term S_i is a random offset for site i from the regional baseline μ and this terms accounts for between site variations. The model assumes site effects follow a normal distribution with between site variance τ^2. The final term $\varepsilon_{i,j,t}$ captures within site variation which can be attributed to both measurement error and local spatial variation. We assume this follows a normal distribution with within site variance σ^2. Also the site effect and measurement errors are assumed to be independent of each other.

In statistical notation:

- S_i ~ Normal(mean = 0, variance = τ^2)

- $\varepsilon_{i,j,t}$ ~ Normal(mean = 0, variance = σ^2)
- S_i and $\varepsilon_{i,j,t}$ are independent

The key properties of this model are as follows. The variance of any individual observation is $\sigma^2 + \tau^2$. The covariance of any pair of observations within the same site is τ^2 but the covariance of any pair of observations from different sites is zero.

We assume that bulking of samples for a Monitoring Site has an averaging effect, so the variance of data from bulked samples is lower than the variance of data from individual samples. When all m samples collected at time point t are bulked prior to measuring soil organic carbon or pH, the model for aggregated data is:

- $Z_{i,t}$ = SOC from m bulked cores at site i at time point t

  i.e. $Z_{i,t} = (Y_{i,1,t} + Y_{i,2,t} + \ldots + Y_{i,m,t}) / m$
- $Z_{i,t} = \mu + S_i + \beta x_t + \varepsilon_{i,t}$
- S_i are independent Normal(mean = 0, variance = τ^2)
- $\varepsilon_{i,t}$ are independent Normal(mean = 0, variance = σ^2 / m)
- S_i and $\varepsilon_{i,t}$ are independent

This statistical inference that arises from this model is based entirely on the assumptions of normality and not on the design based probability sampling of sites in our Monitoring Unit.

The model ignores spatial variability of the soil measurements other than to say that observations within the same site have covariance τ^2. Our wish to achieve spatial coverage across large Monitoring Units will require that the distances between most pairs of sites be large and our independence assumption between different sites will not be violated. Should two sites be located next to each other this assumption would break down but it is not likely that sites will be close to each other. If two sites are close to each other then the data from one of the sites could be excluded from analysis or alternatively, the statistical model can be altered to incorporate both data from both sites. If exclusion is the preferred approach, then there is no point in collecting data for both sites in the first place.

Under the assumptions of the statistical model it is the within site variance term σ^2 not the between site variance term τ^2 that affects power calculations, the variability of our estimate for trend β and ultimately on the change in response over a twenty year period. Power calculations for this model are unaffected by whether or not bulking takes place as the model assumes bulking is an averaging process.

Finally the power of our monitoring scheme depends on the total number of samples collected at each time point (the product of the number of Monitoring Sites and the number of samples collected at each site). So a monitoring scheme involving twenty sites with ten samples at each time point is as powerful as a monitoring scheme involving forty sites with five observations at each time point.

However the within and between site variability will need to be estimated from the data. As such to have too few samples within sites will impinge upon our ability to estimate σ^2. On the other hand, having too few sites will reduce our the spatial coverage so for practical reasons a balance between the number of sites and the number of samples collected within sites will be required.

As reported by McKenzie *et al.* (2002), the most powerful approach to monitoring over a twenty year period would involve collecting half the data at the start and the remaining half at the same sites after twenty years. This will give us the greatest probability of detecting a change over this period. However this gives no interim information and no insight into the nature of the change.

Prior to establishing the monitoring scheme we can use estimates for σ^2 to choose the appropriate number of sites. The number of sites can be updated when estimates of σ^2 are obtained from the initial sampling for this project. When the actual data is ready to be analysed the terms σ^2 and τ^2 can be estimated using easy to use open source statistical software available online. Based on the estimates of these variance terms, empirical estimates for μ and β can be found together with their standard errors. Details for the analysis are available below.

3.2.1. Questions and clarifications about the statistical model

This statistical model may raise many questions, and those asked to date are responded to here.

Why should we carry out probability based site selection if the analysis is not based on the design? Probability based designs are a way of selecting monitoring sites randomly across space (e.g. by simple random sampling or stratified random sampling). The principal reason for choosing our sites randomly is to protect us from any unintended bias being introduced by the selection of sites and, in the case of stratified random sampling, to ensure spatial balance across the region of interest. Horvitz and Thompson (1952) illustrate how data collected from such a design can be analysed without making distributional assumptions for the response variable. We choose to make additional assumptions (such as the assumption that samples within the same site are correlated) to better mirror reality as well as assumptions of normality. These additional assumptions are open to criticism. An analysis based on the probability design would not be open to such criticisms.

Why measure cores individually if bulking has no effect on inference? This model states simply that all observations with a particular site have covariance τ^2 regardless of how close the corresponding samples are positioned with the site. It is possible that this is an oversimplification of the nature of spatial variation in soil measurements. If we wish to get a better understanding of sub-site spatial variability we will need observations associated with individual core samples.

Can we analyse data that is bulked for some sites and not for others? What if we fail to revisit one site at a particular time point? What happens if we only collect nine core samples instead of ten? What if a site drops out the monitoring scheme entirely? All of these issues are important but none are fatal. All data collected as part of this study should be retained even if a site is only visited once. The information will still contribute to the estimation of the variance terms σ^2 and τ^2. Keep track of the number of cores bulked together for each observation. All data are modelled simultaneously.

Can we also fit more modern spatial models where the covariance between each pair of observations is a function of the distance between the corresponding locations? This would also be possible with these data, though inference about the parameters associated with the spatial model might be better estimated if sites are not distributed evenly across our region (Zhu and Zhang 2006). Such models enable the user to create maps of the soil property across the region, as well as providing standard errors associated with our predictions across space. The standard error associated with the trend term is likely to be lower. These models are not as easy to fit as the models specified in this report, and careful attention needs to be paid to the family of spatial models chosen. One should also keep track of locations of cores within sites regardless of whether cores are bulked or not.

Can we design this monitoring scheme with a particular spatial model in mind? If data is available to estimate spatial parameters then we can choose sites that will optimise subsequent analysis. A flexible family of spatial models such as the Matern class of spatial covariance functions should be used to achieve this. Spatial models may struggle to capture sharp discontinuities in soil properties, especially in regions with limited numbers of monitoring sites. Such potential limitations are not applicable for non-spatial models because they do not attempt to produce maps in the first place.

Can we use existing monitoring sites within this study? By selecting sites randomly we avoid unintended bias by using the information at those sites to infer what is happening on average across the whole space. If legacy sites are not representative of the space then admitting them will clearly introduce bias to the monitoring scheme. However, assuming the sites are representative of the Monitoring Unit of interest and the method of data collection used at the sites is the same then there is no reason to exclude them. Ideally access to historical data will come hand in hand with the use of legacy sites. To ensure comparability of historical and new data, the soil core size, method of soil extraction, method for laboratory analysis etc should be similar.

Does the time interval between sampling events have to be the same for all sites within the monitoring unit? No, the statistical model is flexible and can handle sites within a monitoring unit sampled at different time intervals; therefore some sites can be sampled more intensively e.g. yearly intervals, while others can be sampled on 5 or 10 year intervals. For comparability of numbers the soil samples should be collected within the same season.

What is the minimum detectable change, the level of confidence that we are testing for and the chance of the scheme succeeding to detect such a change when it exists? This will depend on monitoring units and the time periods in question. For some soil types a small change from a low base level will be very important to detect whereas a small change in magnitude from a high base level may be of less importance. The achievable level of confidence will depend on the variability of the soil type; some soils for a monitoring unit may be tightly defined whereas others may cover a large range. The variability will determine the number of sites required for achieving a certain level of confidence together with the power to detect an actual change. It is possible that the number of sites required may be beyond the resources available.

3.2.2. Storing of Information

An example dataset highlighting the minimum information requirements for fitting the model are shown in Table 3-1. The code (shown below) for fitting the statistical model assumes the information is available in csv format (a common export option for many monitoring databases). The csv spreadsheet should contain a single row of data for each measurement from the soil. The spread sheet may look something like what is presented in Table 3-1:

Data Value	Site ID	Time (years)	Bulked
1.35	Site A	0	1
1.45	Site A	0	1
:	:	:	:
2.35	Site A	0	1
1.48	Site A	5	5
2.13	Site A	5	5
1.78	Site B	0	2
3.01	Site B	1	3
2.47	Site B	5	10
4.21	Site C	0	10
3.76	Site C	10	1
:	:	:	:

Table 3-1. Example of data files structure for input into the statistical model.

Associated with each recorded measurement is the site from where the soil sample was collected, the time the sample was collected and the number of core samples that were bulked together prior to recording the measurement. The second column should be alpha-numeric and the other three should be numeric. Additional information on land use, land management and other site characteristics may also be included in our analysis.

3.2.3. Fitting the Statistical Model

There are many software packages available to fit this statistical model to the data outlined above. One way to do it is to use the open source R environment for statistical computing (R Development Core Team 2010) which is freely available online from

http://www.R-project.org. Download and install R together with the package regress (Clifford and McCullagh, 2006). If the data is stored in the file "data.csv" the commands required to fit this model are as follows:

```
library(regress)
data <- read.csv("data.csv")
V <- diag(1/data$Bulked)
is.factor(data$Site) ## check, should be True
model <- with(data,regress(Y~1+Time,~Site + V,identity=FALSE))
summary(model)
```

These commands fit the model by maximising the residual log likelihood of this model. The output from these commands will indicate the estimates of the time coefficient together with its standard error. A 95% confidence interval for the trend term β can be computed as the point estimate ± 2 x standard error.

3.2.4. Specificity and Sensitivity of Monitoring

The discussion of any monitoring scheme would be incomplete without a discussion of the specificity and sensitivity of the scheme. These terms refer to how likely the monitoring scheme will find false-positive and false-negative results. The goal of monitoring is to estimate how much the response has changed and for many Monitoring Units (see below) there are desired minimum detectable changes already specified – see McKenzie *et al.* (2002)

We wish our scheme to have a low (typically 5%) chance of finding a false-positive. In this example, a false-positive would occur if we conclude that we have significant change when in reality there is none. This kind of error is controlled by using 95% confidence intervals when estimating the change in response. There is a 5% chance that such a confidence interval for change in response will not contain zero when in reality the change is zero.

On the other hand, a false negative will occur if the true change is different from zero but we fail to detect it, i.e. our 95% confidence interval for change includes the value zero. A power analysis examines how likely this will happen if the true change in response is equal to our minimum detectable change. Power levels for this statistical model are affected by the number of monitoring sites, within site variability and the desired minimum detectable change in response. By specifying the desired minimum detectable size and using our knowledge of the within site variability we can show how changes to sample size affect the power of our monitoring scheme (see Figure 3-3).

3.3. Spatial elements

The National Soil Condition Monitoring Program consists of the following hierarchical elements organised as indicated in Figure 3-2.

Monitoring Region – is the primary stratification, which together constitutes the geographic extent of the country and is monitored for national reporting. The Monitoring Regions chosen represent a cross-section of the major Australian agro ecological zones, where the range of parent material, geomorphology and climate is constrained.

Monitoring Unit – is the primary segment of monitoring, where soil characteristics, climate and land use are relatively uniform and it is expected that changes in soil condition indicators would be of a similar magnitude for similar management actions. The Monitoring Units chosen will constitute a specific subset of the land management systems in the country and will be representative of current practice or some designed changes to current practice to achieve specific environmental purposes. The soil type is defined according to the Australian Soil Classification for Order level (http://www.clw.csiro.au/aclep/asc_re_on_line/soilhome.htm) and further refinement to describe the type of soil material and its range of properties that will constitute the soil concept for monitoring, and the land use is defined according to the Australian Land Use and Management (ALUM) Classification (http://adl.brs.gov.au/mapserv/landuse/index.cfm?fa=app.classes&tab=classification).

Monitoring site – is a single expression of a Monitoring Unit within a Monitoring Region (that is a single soil type by land use/management practice combination). Monitoring Sites represent the base unit in the national monitoring program. Many Monitoring Sites would be established within each selected Monitoring Unit.

The Monitoring Site will be a 25 m by 25 m square that covers a total area of 625 m^2. The detection of temporal trends will be advanced by ensuring that Monitoring Sites are as representative as possible. Note, this is different to the Monitoring Site being as homogenous as possible, what is required is that the Monitoring Site represents the Monitoring Unit and if the soil for the Monitoring Unit is overall highly variable, then so to should the Monitoring Site. This size and shape is selected as it was determined to be "both pragmatic, consistent with the established site concepts (NCST 2009) and provides room for repeated sampling" (Baldock 2010) and follows on from the recommendations by McKenzie *et al.* (2002).

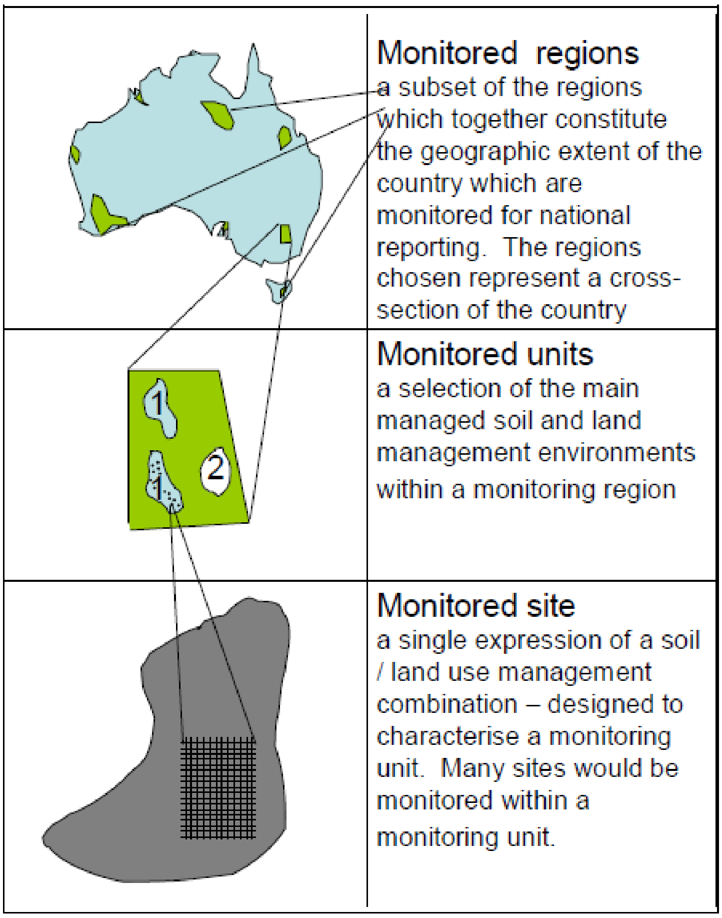


Figure 3-2. Diagrammatic representation of the hierarchical organisation of Monitoring Regions, Monitoring Units and Monitoring Sites within the national soil condition monitoring program.

3.3.1. Monitoring Regions selected

The initial approach and identification of potential Monitoring Regions was described in Baldock *et al.* (2010) and the process for selecting Monitoring Regions across Australia involved grouping of physiographic regions defined and delineated by Jennings and Mabbutt (1986) according to:

- Classification of soil properties – to allow regions with similar soils to be identified and grouped to ensure that selected regions covered the range of soils, and to avoid Monitoring Regions from being selected from the same group or a narrow range of groups.
- Allocating priorities for the degree of land use intensity – to allow regions to be identified where the land use was agriculture and covering a sufficient extent of the physiographic region.
- Potential resilience of the soil to change – to allow regions to be identified that are most likely to be at risk of degradation or potentially an early indicator of change.

The Baldock *et al.* (2010) report identified 20 potential Monitoring Regions to be used as a starting point. Further refinements to this selection were conducted by using the Atlas of Australian Soils boundaries which provided improved spatial detail, consideration of the investment priority regions (CSIRO 2009a, CSIRO 2009b), and assessment by experts from each jurisdiction.

The list of selected Monitoring Regions is presented in Appendix A.

3.3.2. Monitoring Units selected

Monitoring Units are discontinuous areas of land with similar soil and land use combinations that are geographically constrained by the Monitoring Region.

The Monitoring Units were determined by the responsible agencies in each jurisdiction by considering:

- The Monitoring Region classification that identified priority areas that are potentially vulnerable to change in soil pH and/or soil organic carbon, these are identified in Baldock *et al.* 2010. This classification provided guidance.
- The region classification reworked using the Atlas of Australian Soils unit boundaries to provide a finer level of detail.
- The assessment results to determine priority areas for managing soil pH and soil organic carbon for Caring for our Country investment (CSIRO 2009a, CSIRO 2009b).
- Expert knowledge from the responsible agencies that considered the jurisdiction direction and priorities for land management, and their understanding of areas that may be vulnerable.
- Narrowing down to particular target land uses and vulnerable extensive and important soil types within the regions

The list of selected Monitoring Units is presented in Appendix A.

3.3.3. Monitoring Sites selected

Monitoring sites are the locations from where the 25 m by 25 m areas for soil sampling are selected. They are determined by randomly identifying areas that occur within the Monitoring Unit.

There are many ways in which the location of a Monitoring Site can be selected without bias. A suggested approach includes:

- Delineation of the Monitoring Unit spatial extent within the Monitoring Region – using the available soil and land use information. It is likely that these will identify multiple discontinuous areas of land.
- Random generation of coordinate locations within the Monitoring Unit –the approach should be random, quantitative and described explicitly, such as:
    - generate a 25 by 25 metre grid of cells (or any other uniform size such as 1000 by 1000 metres) that are not overlapping across the Monitoring Unit area,
    - generating a list of coordinates for the southwest grid cell corner,
    - randomly sort the coordinates, and
    - then work through the list from the first coordinate down to the last ,until the required number of Monitoring Sites has been established.

Map Unit impurities (components)

It is recognised that in Australia soils have generally not been mapped at sufficient detail to facilitate the delineation of pure soil units. In many cases the mapping units are generally soil-landscapes that contain a range of soil types. The assemblage of the soil types within the soil map unit may be understood and described in the map legend and documentation. If the pattern of soils is known and related to the landscape then additional terrain information could be introduced as another information layer to fine-tune the Monitoring Unit location.

Regardless of how the Monitoring Unit area is delineated it is likely that it will contain locations that do not meet the Monitoring Unit concept. When this is determined (by either an initial desktop study or field inspection) the reason for the rejection of the potential Monitoring Site should be specified. Then move down the list to the next randomly selected Monitoring Site location.

Stratification of Monitoring Unit

Generally the Monitoring Unit would be relatively uniform and everywhere within the unit has an equal probability of being selected as a Monitoring Site; then it is unlikely that further stratification is required to ensure equitable distribution of sites across it.

For some Monitoring Units further stratification may be appropriate, such as: by climate (rainfall zones), by individual monitoring units areas, by positions in the landscape, or by using all available environmental and remote sensed data sets, possibly including time series data and conducting a Latin Hyper-cube analysis to identify key clusters to measure.

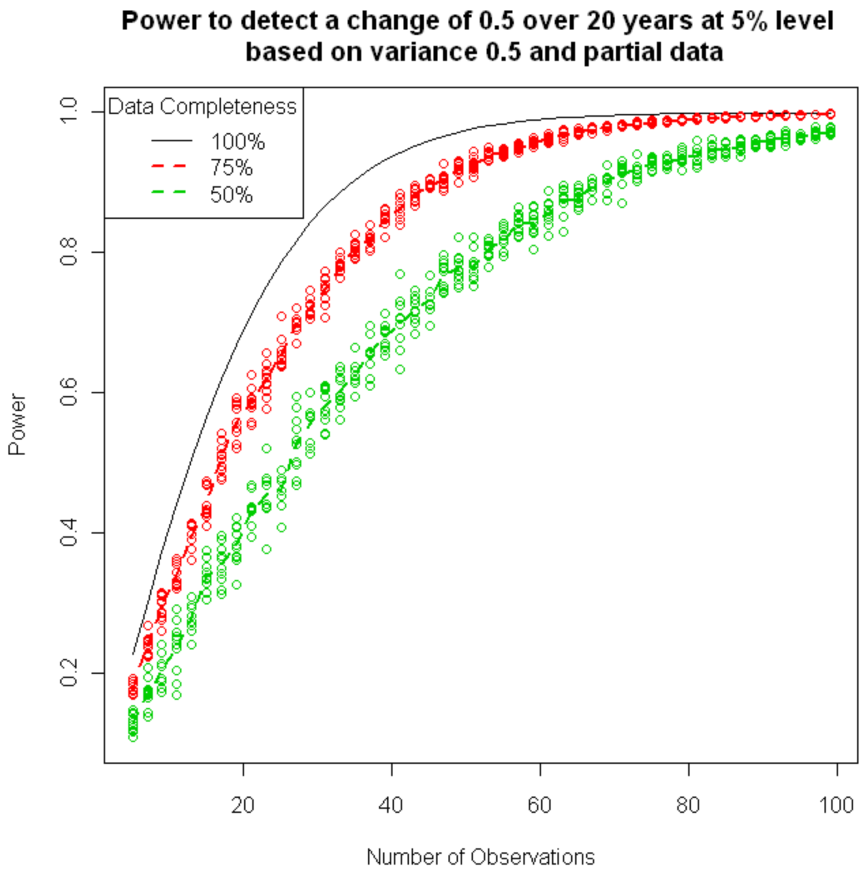
3.4. How many Monitoring Sites are required?

The number of Monitoring Sites required within any given Monitoring Unit will be specified on the basis of a statistical analysis of the known or estimated soil property variance and the magnitude of the minimum detectable change for the response over a specified time period. Based on these two values, the number of monitoring sites should be set so that the power of our model is 80%. To determine the number of Monitoring Sites, prior data is required for analysis. Investigations were made at the start of the project to identify and obtain data sets for each of the Monitoring Units but either there were none available or there was insufficient suitable data. Calculations of the number of sites required could not be made and will need to be determined after an initial round of sampling to provide a data set for conducting the analysis.

To establish guidelines for cost estimate and planning purposes the dataset in McKenzie *et al.* (2002b) was used. Assuming observations have a within site variance of $\sigma^2 = 0.5$, the relationship between power and the total number of observations is shown in Figure 3-3. This is for a minimum detectable change of magnitude 0.5 over a twenty year period. When we have 25 observations collected every five years over a 20 year period the power is just under 80%.

As always, the more observations you have at each time point the more likely we are to detect a true change in response over time. The red and green points in Figure 3-3 highlight how power can be reduced if only a portion (75% or 50% respectively) of the data are collected over the course of the study. The particular portion missing will affect the resulting power – hence the scatter in the red and green points shown in Figure 3-3.

Figure 3-4 summarises and quantifies the relationship between power, minimum detectable change and number of monitoring sites when the within site variance is $\sigma^2 = 0.5$. The lines plotted show how power changes with sample size for a given minimum detectable change (as indicated in red beside each line). This plot assumes the full set of data is gathered at each time point so the curves here for effect sizes 0.2 and 0.5 are the same as those in the two Figure 3-3 graphs above.



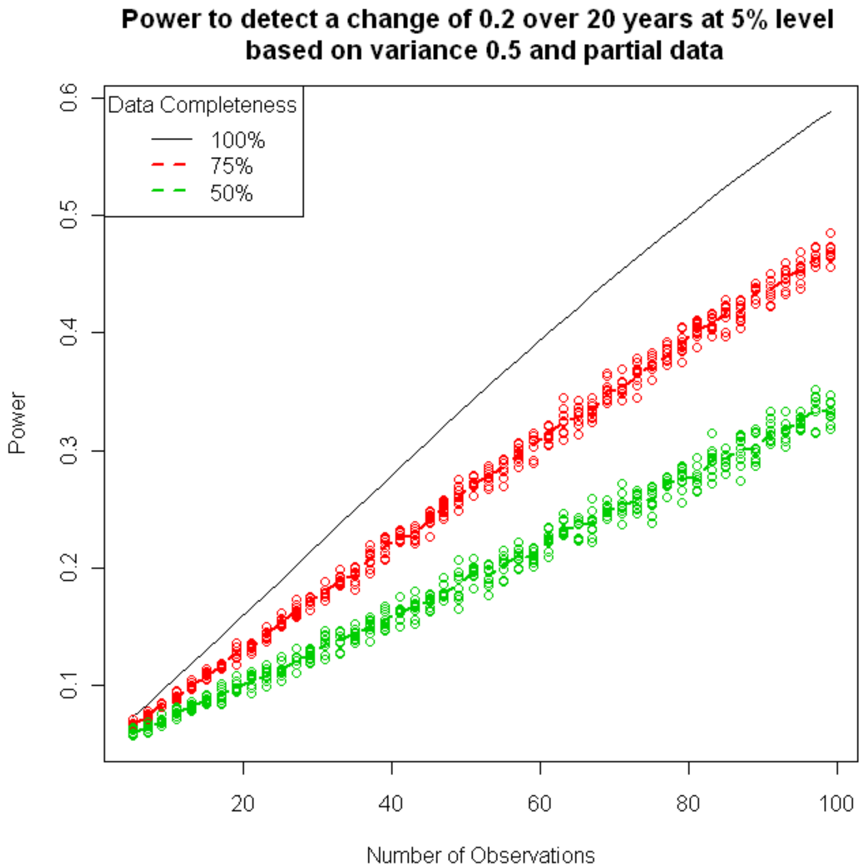


Figure 3-3. The graphs shows the power to detect a change of 0.5 or 0.2 over 20 years at 5% level based on variance 0.5 and partial data.

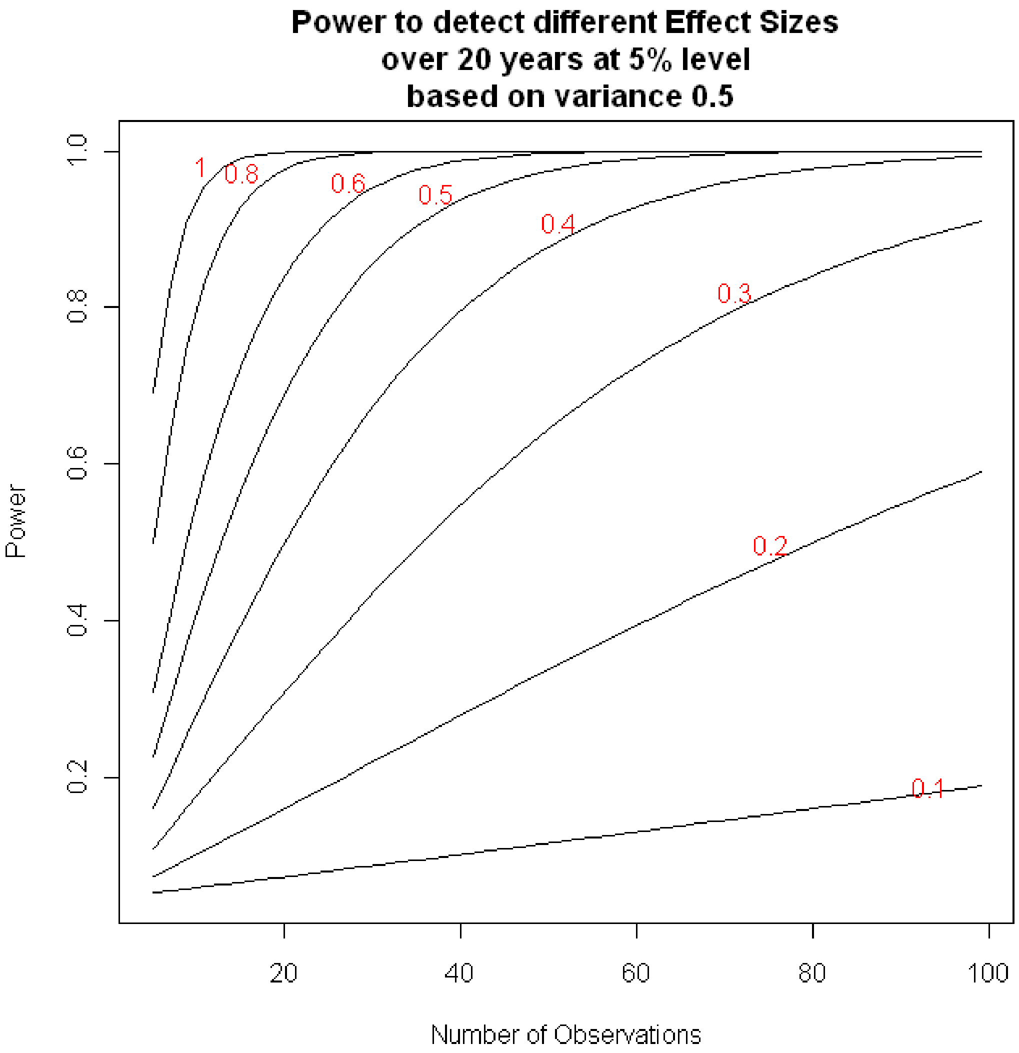


Figure 3-4. The graph shows the power to detect different minimum detectable change values (effect size) over 20 years at 5% level based on variance 0.5.

What is an effect size?

Another way to look at things would be to fix the power at 80% say, and see how the total number of observations affects the minimum effect size that we can detect at the 5% level of significance? Again here it is assumed a variance of 0.5. As before, the more data you have the better (smaller minimum effect size). Also the red and green points show how a reduction in the number of observations will affect the minimum effect size that can be detected with a power of 80%.

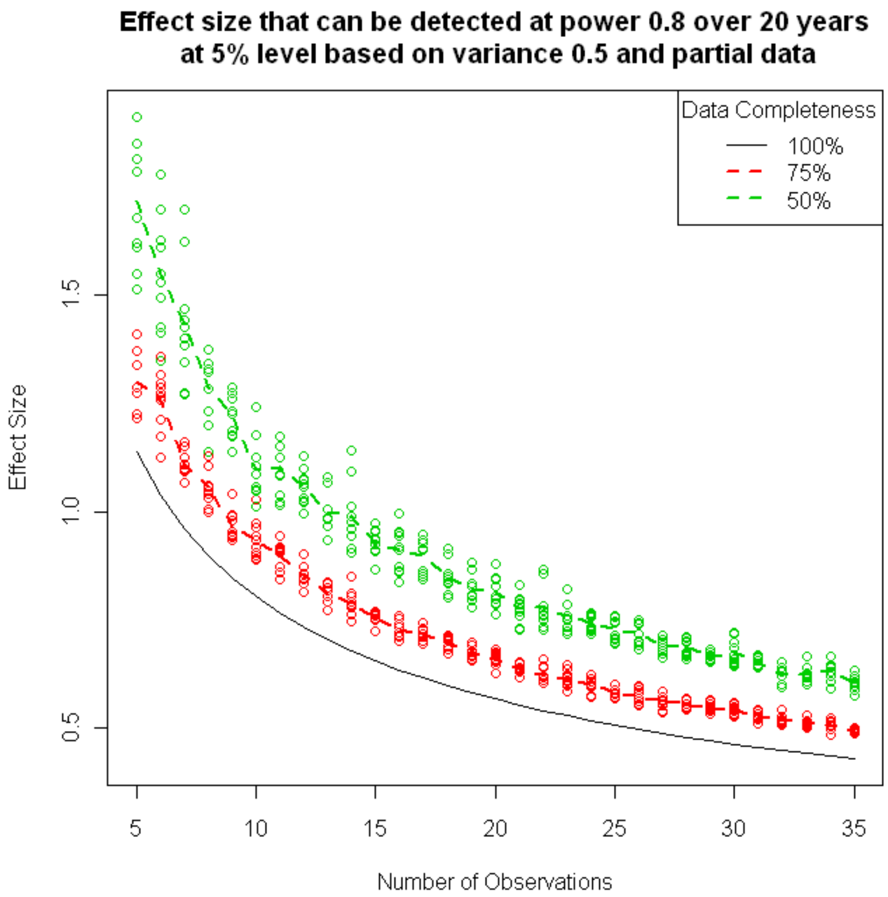
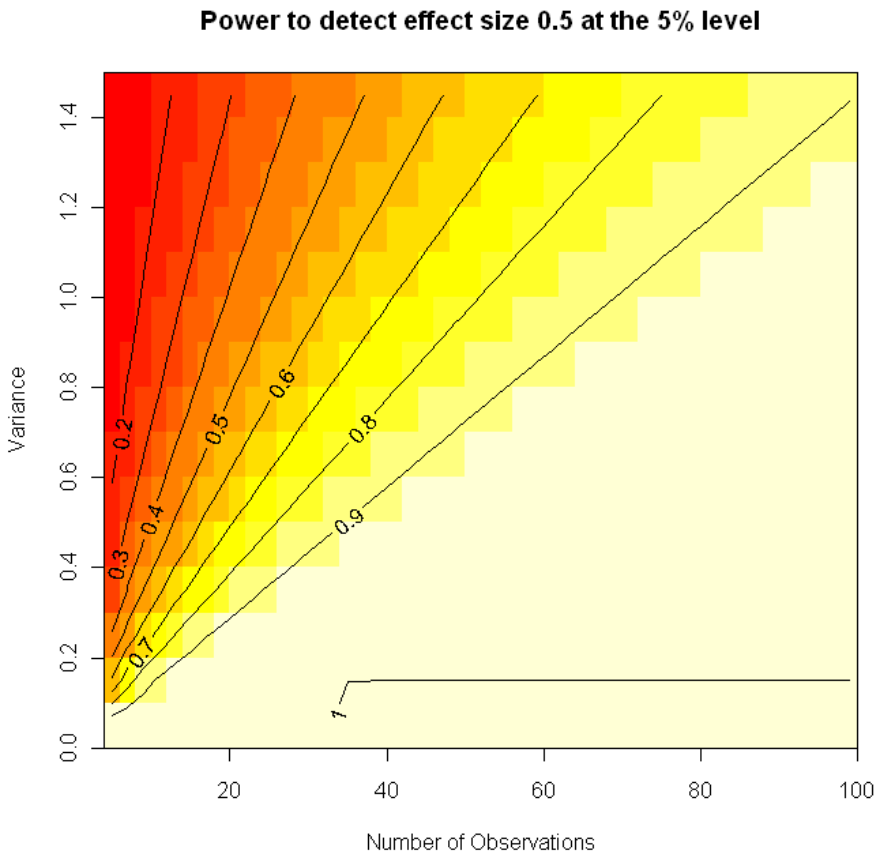


Figure 3-5. The graph shows the minimum detectable change values (effect size) that can be detected at power 0.8 over 20 years at 5% level based on variance 0.5 and partial data.

Ignoring the possibility that some data will not be available we can also look jointly at the effect of variance and sample size on power for a specific effect size as well as the examining the effect of variance and sample size on minimum effect size for a specific power. This can be summarised via image maps (whiter colours correspond to higher values) and contour plots. Examples of this are shown in Figure 3-6.



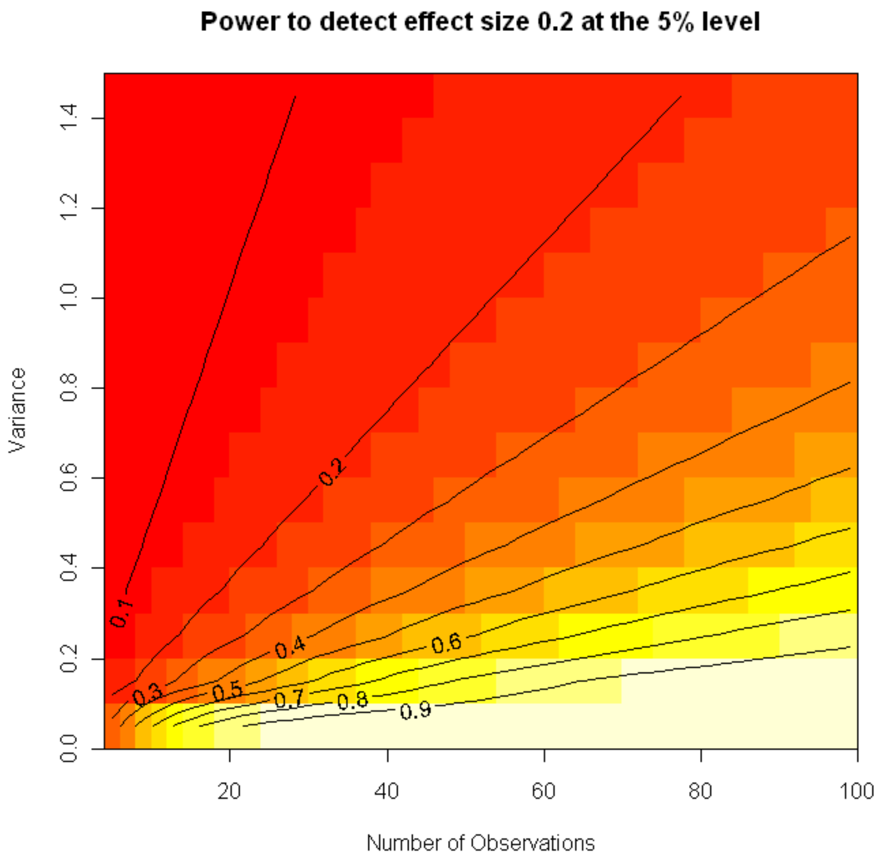


Figure 3-6. These plots show the power to find a minimum detectable change values (effect size) of 0.5 or 0.2 at the 5% level.

Throughout the examples above we are assuming testing is to be carried out at the 5% level and sampling is carried out every five years over a 20 year period. All these examples essentially say that a decrease in the number of observations (which we can control) or an increase in the variance (which we cannot control) will reduce the power to detect a specific effect size. Put another way, it will reduce the effect size that we can detect with a specified power.

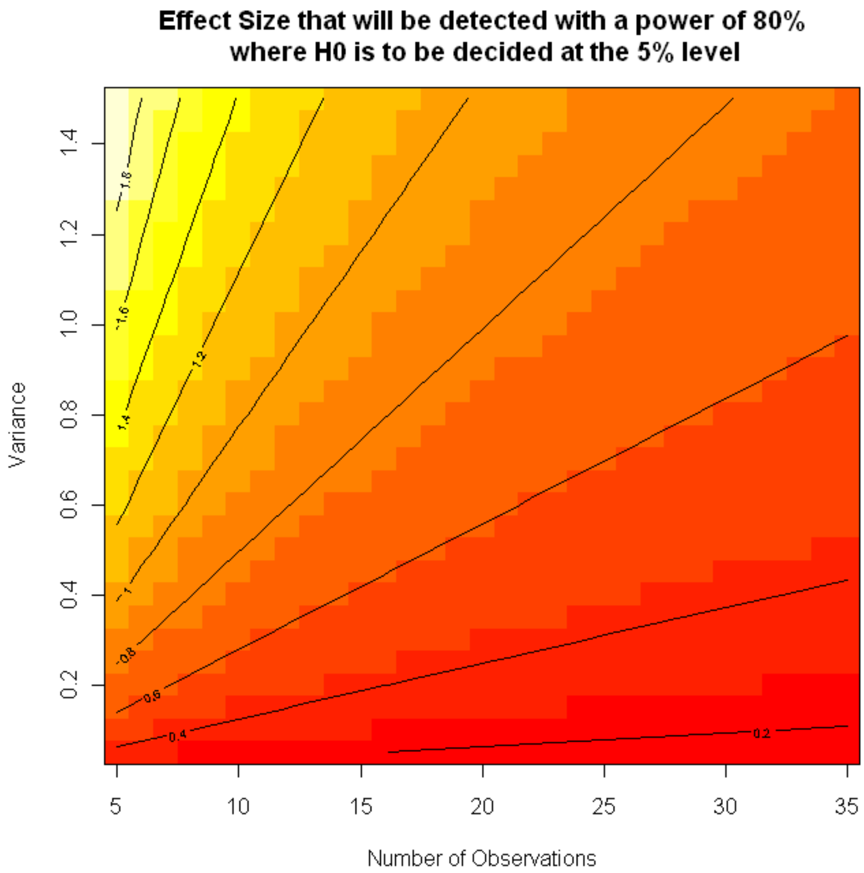


Figure 3-7. The plot shows the effect size that will be detected with a power of 80% where H0 is to be decided at the 5% level.

3.5. Number of soil samples per Monitoring Site

The number of individual soil samples to be collected at each Monitoring Site is 10 for each sample depth. For some sites, the 10 individual samples will be bulked in the field and then analysed as a bulk soil sample, at other sites they will be collected and maintained as individual samples to be analysed. The proportion of Monitoring Sites within a Monitoring Unit to bulk will be determined as data about the Monitoring Unit becomes available and the resource constraints are considered, particularly as the cost increases ten-fold if 10 individual samples are to be processed and analysed versus one bulk sample.

As described above the statistical model can process data for a Monitoring Site from samples that are bulked and/or individually collected samples. The additional information obtained from analysing individual samples includes providing data on the short-range variability and information on the variance about the mean of the soil property at a site.

4. DATA COLLECTION

Collection of a valid data set for analysis is the key to the success of the National Soil Condition Monitoring Program. A summary of the key points for data collection is provided in Table 4-1, and these are expanded on in the following sub-sections.

Table 4-1. A summary list of the key points for data collection.

Action for data collection	Comment
Verify that the site is suitable • Office desktop study • Landowner contact • Site inspection • Rules for site relocation	Prior to conducting field work, confirm that the site is suitable as a long-term Monitoring Site.
Establish the Monitoring Site • Seasonal timing • Site layout – perimeter • Site layout – internal	Sample when the rate of change is expected to be minimised and access is permitted. Square shape of 25 m by 25 m (total area 625 m^2). 2.5m by 2.5m grid, sample locations at grid intersections.
Monitoring Site position	Identified by the coordinates of the southwest corner of the sampling site. Measure to sub-metre accuracy using a differential global positioning system (DGPS).
Photographs	Digital photographs taken of the Monitoring Site, soil profile to at least 30 cm and of the landscape features.
Soil characterisation (conducted on first visit only)	Characterisation site located at the south west corner of the monitoring site. Landscape and soil profile described according to the 'Australian soil and land survey field handbook' (NCST 2009) and the Australian Soil Classification (Isbell 2002). Photograph soil profile and sample soil for laboratory analysis (see Section 4.4).
Soil sample locations	10 sample locations randomly placed at grid intersections. Once an intersection has been sampled it is removed as a future sample location.
Sample depths Sample volumes	Three depth increments at each soil sample location. 0 to 10 cm, 10 to 20 cm, and 20 to 30 cm. Samples are collected as a stack (that is, they are collected directly below where the above sample was collected from). Collection of soil sample is over the depth range and horizon boundaries are not considered. For some Monitoring Units deeper samples may also be required, such as if subsoil pH is to be monitored. For subsequent sampling events, a 4th depth 30 to 40 cm will be required if the bulk density in the 0 to 30 cm depth has decreased, this allows standardising to the original bulk density values for comparison. Soil samples collected within a site should be the same volume. This is critical for sampling events where the samples are bulked.

Action for data collection	Comment
Soil sample collection	Soil sample is collected for the entire depth increment. For the early sampling events the samples are to be bagged individually for sample analysis. For later sampling events once sufficient information is available on the within site variability the samples at the same depths may be bulked for the monitoring site.
Bulk density sample collection	Samples obtained as part of the soil sample collection are also used for bulk density determination. If this is not possible then three cores are collected at a minimum of three locations for each depth range.
Land management record	Standard survey form to collect information about land management and land management history from landowner.
Laboratory analysis	Conducted at a Central Soil Analytical Laboratory or by laboratories that meet specified standards.
Soil organic carbon analysis	Includes all or some of the following analyses: • Total carbon analysis • Sample pre-treatment to remove carbonate carbon • Fractionation of soil organic carbon – direct method • Fractionation of soil organic carbon – indirect method
Soil pH analysis	Includes all or some of the following analyses: • Soil pH in calcium chloride • pH buffering capacity by Mehlich buffer method • pH buffering capacity by titration
Bulk density analysis	Weight and volume of sample measured to determine density.
Repeat sampling event	Conducted at least every 5 years
Rejected sites	Excess sites generated in the initial random identification process to accommodate unsuitable sites.
Exhaustion and replacement	Excess sites built in to the program to replace abandoned sites, either as additional established sites or identification of additional locations to be established as required

4.1. Verify that the site is suitable

The Monitoring Site locations are predetermined as described in Section 2.5.

Prior to the establishment of a Monitoring Site a number of factors should be considered to verify that the site is suitable. This is to be conducted according to the following three stages:

1. Office desktop work
2. Landowner contact
3. Site inspection

If all the criteria are met then the site is suitable for establishing. If some of the criteria are not met then there may be an opportunity for the site to be moved based on the listed Rules for Site Relocation (Section 5.1.4). If the predetermined site is not suitable and cannot be relocated then it is rejected and the next site is selected from the random list.

4.1.1. Office desktop work

Prior to commencing field investigations the predetermined monitoring site location is to undergo a desktop evaluation to verify that it is potentially a suitable site to be part of the National Soil Condition Monitoring Network. The desktop study using imagery, map information, existing reports and other information should confirm at a minimum the following points:

- The site is located in an area that meets the requirements of the named Monitoring Unit with regard to intent of the soil type characteristics and land use.
- Confirm that the site could be accessed safely.
- Identify historical data that may provide background information to support or dismiss the location as a potential long term monitoring site.
- If there is uncertainty about the sites suitability at this early stage, a drive by to observe the general area may be necessary and/or contacting people who may be knowledgeable about the area.
- Identify the landowner and obtain contact details.

4.1.2. Landowner contact

Prior to the initial field sampling, the landowner is to be contacted to explain the program, obtain permission to establish a long-term monitoring site on the property that can then be revisited in the future, confirm soil type and land use, and obtain information regarding access to the proposed site.

Points of discussion and information to obtain from the landowner should include the following:

- Explain that the site would be part of a long-term National Soil Condition Monitoring Network. The site will provide baseline information about the soil and in the future the site will be revisited (approximately every 5 years) for further sample collection that will be used for monitor the soil condition.
- Briefly explain the work that would be conducted. The site established will be a 25 metres by 25 metres area, there will be minimal soil and surface disturbance to collect small (50 mm diameter) core samples at 10 locations within the site, and the site will be revisited for at least the next 20 years at about 5 year intervals to conduct similar sampling.
- Confirm that permission is provided for the current sampling and that future sampling would presumably be acceptable. If the landowner is not supportive then the site is rejected.
- Confirm that there is no immediate plan to change the land use of the paddock where the site is located. If there is a plan for change, then a decision is required to determine if the change is significant enough that the site would no longer meet the Monitoring Unit concept, and the site would be rejected. Changes to land use practice (for example from conventional tillage to no-till) may be acceptable.
- Advise that if the landowner would like to have the soil test data results then this will be made available, but there will be a delay (between 6 and 12 months) between sampling and providing results because of the large volume of soil samples to be

tested and evaluated. There is a need to limit the information provided with the soil test results and take measures to ensure that the information does not cause action to occur which would not have been otherwise undertaken and hence ruin the representative integrity of the site.

- Discuss the landowners understanding of the land use and soil features at the site and within the paddock.
- Obtain/confirm contact details – mail address, phone / fax number and email address.
- Identify best access, access issues, and if vehicles can be taken through the property to the site location or where the nearest suitable vehicle stopping location would be.
- Advise that it will be necessary for the landowner to complete a land management survey about the paddock where the site is located.
- Record any questions or concerns that cannot immediately be answered and provide an acceptable timeframe when they will be responded to.
- Emphasise that findings will be reported for each Monitoring Unit (soil type by land use) and Monitoring Region (large physiographic area), which involves many sites across many farms. Individual property data and maps will not be identified in the reporting.
- Emphasise that the project depends on normal land management practices being conducted and that it is important that the site location is not given any special attention or treatment.
- Currently there is no national monitoring program to provide information and guidance on soil health. This is a long-term program (20 to 50 years or more) to provide base-line information and monitoring of change in soil condition that will assist state and national allocation of resources to maintain and improve soil health.
- A handout that explains the soil monitoring program will be provided (handout to be prepared).
- Identify the jurisdiction representative for the Monitoring Program who is available to provide further information.

4.1.3. Site inspection

Prior to the initial site establishment and field sampling it is necessary to confirm that the site is representative of the Monitoring Unit and suitable for establishment. Mark out the general dimensions of the Monitoring Site location and walk over the area.

The site inspection is to be conducted first to ensure the following requirements are met:

- The land use at the site and the paddock where the site is located in corresponds with the Monitoring Unit description. Determined by visual observation of the land use over the site area. If the land use is rotational (for example crop, crop, pasture, crop) then the current stage of the rotation and the past history of the paddock should be verified by discussions with the landowner. The site should occur within an area representative of the paddock so that the management across this area is consistent with that recorded for the paddock history. If the area is not representative then consider relocation of the site according to the rules in Section 5.1.4. If the land use does not meet the Monitoring Unit description then the site is rejected.
- Soil type at the site corresponds with the Monitoring Unit description and is reasonably representative across the site area. Determined by pit/auger observations through the proposed site area and visually assessing the soil texture, colour, consistence and structure, for both the topsoil and subsoil layers. The number of check observations of the soil required will be at the discretion of the senior soil surveyor, but it is recommended that a minimum of four quick observations

at the corners of the proposed site location are made. Care should be taken to keep the soil disturbance to a minimum so as not to interfere with the monitoring sample collection locations. If soil variability across the site is not within the expected concept limits then consider relocation of the site according to the rules in Section 5.1.4. If after relocation the soil type still does not meet the Monitoring Unit criteria then the site is rejected.

- The site is not significantly influenced by extra traffic movement other than normally would be expected in the paddock as a whole. Determined by visual observation to identify if there are factors that would necessitate a site to be relocated, examples include site location is near a gate, at the end of a field where turning occurs, near firebreak around field, near obstacles (rocks, trees, stream line), or near infrastructure (dams, water trough, silo, buildings, pipelines, power lines). If the area is not representative then consider relocation of the site according to the rules in Section 5.1.4.

4.1.4. Rules for site relocation and rejection

If the predetermined site location is not suitable as a Monitoring Site then it can be relocated, but it must be relocated without bias. To ensure this occurs in a standard way the following rules regarding relocation are to be applied:

- For pragmatic reasons the relocated site should be placed within the same farm boundary as the original site location, allowing the landowner contact to be maintained.
- The relocated site should be relocated randomly following a prescribed method. For example, the next location to be evaluated is to be placed 50 m from the original location on a bearing towards the centre of the paddock, this should continue at 50m intervals until a suitable site is identified or up to a maximum of 300 m away from the original site location. If a suitable site cannot be identified then the site is rejected,
- Ideally the relocated site should occur within the same paddock and same "soil" map unit as the original Monitoring Site.

If the above rules do not allow for a suitable monitoring site location to be identified then the site is rejected. For a rejected site, the field sheet should be filled in with notes providing the reason why that site is not to be used. The following should be recorded:

- Region name
- Monitoring Unit name
- Site number
- Coordinates of intended site location
- Actions taken to relocate the site
- Reason/s for not using the site location, which could be one or more of the following list:
    - permission to access not provided by landowner
    - not a safe work area or access due to …
    - wrong soil type, soil type is … and differs from the required by ….
    - wrong land use, land use is …
    - site is too disturbed to be representative of the typical land use of the paddock.

4.2. Establishing the site

4.2.1. Occupational health and safety

Your employer has obligations to you under relevant Occupational Health and Safety legislation. If you are self-employed, you also have duties under this legislation. While this protocol document is provided to assist with conducting the work, it is you and your employer's responsibility to assess the risks and implement controls whilst conducting the work. You must follow your employer's policies and procedures as they apply to the tasks that you are involved in throughout the project work. This assessment should also include any risks to the public and landowners and if any occur then they should be identified and action taken to mitigate the risk.

4.2.2. Equipment checklist

The equipment to conduct the field work and sampling of soils at a monitoring site is listed in Table 4-2. The list is not exhaustive but provides guidance as to the equipment that potentially be required.

Table 4-2. List of equipment potentially required to conduct field work at a soil monitoring site.

Item	Number	Rationale and Comment
Documents and Electronic Equipment		
National Soil Condition Monitoring Protocols report	1	Outlines methods and procedures.
Field data recording sheet	1	Recording details of positions and soil layers that are sampled.
Field notebook	1	For recording ad hoc notes if required.
Soil site and profile description card	1	The agencies standard recording card for characterisation of a soil profile and site.
Australian soil and land survey field description handbook (NCST 2009)	1	Provides national definitions and codes for describing soils.
Map and/or imagery of the site and surrounding location	1	To support navigation to the site and identifying surrounding features.
Brochure that describes the program and provides contact details	1	For the landowner.
Global Positioning System (GPS) and spare batteries	1	Used to locate site and obtain a final co-ordinate of the monitoring site south west corner. Set to Projection UTM, Datum GDA94, Spheroid WGS84 and coordinates presented as Zone, metres East, and metres North.
Digital camera and spare batteries	1	For recording photographs of the site area and soil.

Monitoring Site Establishment		
50m reel tapes	3	For establishing the perimeter boundary (2 tapes), and checking that it is square and then for locating row sample locations (1 tape).
Corner marker posts (star pickets, aluminium, wooden stakes or similar, about 0.5 to 1m high)	4	For marking the corners, assist with holding the perimeter tapes, and providing a visual reference for photographs.
Compass (good quality)	1	For aligning the sampling perimeter north to south and east to west from the south west corner.
Metal hooks (large tent pegs)	6	For holding the tape on the ground at the ends.
Marker flags (on wire or flexible posts or similar)	10	For marking the sample locations (at grid intersection points).
Monitoring Site Sampling		
Core tube (about 600 mm long)	2	Steel tube, with a cutting tip, marked at depth intervals and with a cutting edge.
Sand spear	1	For obtaining samples in loose sand soils.
Wood blocks (or high density plastic block) or an adapter that fits on to the top of the sample tube and can receive the blows of a hammer.	3	To place over core tube when hammering in.
Large hand mallet or sledge hammer	2	For hammering sample core tubes and bulk density cores into the soil.
Core extraction device	1	Providing leverage to pull core out of soil when tight and difficult to extract.
Long screwdriver, or rod or similar	2	For pushing soil out of core tubes if stuck
Tray (such as large diameter plastic pipe cut longitudinally)	1	For receiving the extracted soil core prior to measuring and cutting up.
Tapered paint scraper	2	For accurately cutting core into increments and/or levelling the top and bottom of the soil in the bulk density core.
Vernier or digital callipers	1	For measuring diameter of sampling tube and/or bulk density rings.
Water drum	1	For clean up and decontamination.
Bucket or similar	1	For holding water and cleaning core tube in.

Metal ruler and/or measuring tape	1	For cross-checking sample depths down hole.
Teaspoons (long handle)	5	For retrieving soil sample that drops out of core into hole during retrieval. Or to remove soil that has fallen into the core hole between depth sample collections.
Sample bags and rubber bands	100 plus	For packaging the soil samples and grouping into the sample positions lots.
Labels (preferably pre-printed and duplicated)	100 plus	For sticking on outside of bag and to insert inside the bag with sample (should be waterproof).
Large sacks (or similar)	2	For holding sample bags together for transport to laboratory.
Knee pads	2	Assists with kneeling to work.
Shovel and/or spade	1	For digging to extract cores if necessary.
Mattock	1	For digging to extract cores if necessary.
Bulk density cores	5	Premeasured width and depth for obtaining samples for bulk density measurements.
Paint scrapers	2	For levelling the top and bottom of the soil in the bulk density core.
Characterisation Profile		
Vehicle mounted coring rig and operating equipment (if available and appropriate for the field conditions)	1	For collection of observation and sampling cores to depth of at least 1 metre. May also be used for collection of monitoring samples, if considered appropriate.
Tape measure (at least 2m)	1	For measuring profile depths.
Depth indicator tape (with clearly marked depth units)	1	To provide visual depth increments that can be seen in photographs.
Spray bottle	1	Holding water.
pH kit	1	Measurement of field pH values.
Munsell colour chart	1	For determining soil colour.
Clinometer	1	Measuring slope angle.
Compass	1	Measuring direction.
Knife	1	For investigating the soil pit.
Trowel	1	For extracting soil samples from pit face.
Geo pick	1	For extracting soil samples from pit face.

Shovel and/or spade	1	For digging .
Augers (sand and clay) and handles	2	For extracting soil (if vehicle mounted rig unsuitable or not available).
Personal Gear		
Field clothing (boots, hat, clothing, etc.)		As required for the field conditions and to satisfy health and safe requirements.
Personal protection (sun protection, insect repellent, first aid equipment, etc.)		As required for the field conditions and to satisfy health and safe requirements.

4.2.3. Seasonal timing of soil sample collection

Inter-seasonal and inter-annual environmental variation will influence the state of soil condition indicators. Annual variations reflecting summer/winter, wet/dry and physiological growth stage of plants affect soil carbon levels and, to a lesser extent, soil pH parameters in different but possibly predictable ways (Baldock *et al.* 2010). Guidelines for the seasonal timing of soil sample collection are:

- Sampling is to occur at times when the rate of change is low, for example in a cropping system this would be during the non-cropping and/or fallow phase.
- Sampling of Monitoring Sites within the same Monitoring Unit is to be conducted within as short a time as possible.
- Sampling of Monitoring Sites in the future is to be conducted at the same time of year and in the same cropping season. For example, subsequent sampling events should be post-spring finish and pre-autumn break if the first sampling occurred within these seasonal conditions, rather than being fixed to a calendar date or month.
- Sampling timing needs also to be pragmatic and take into account the practical aspects of collecting a quality soil sample. It may be that a suitable soil sample cannot be obtained after cropping in the summer months because the soil is very hard, therefore consideration needs to be given to sampling at a different time when the soil is moist which may be during the crop growing period, if so then all sites within the Monitoring Unit should be sampled at the same period of time.

4.2.4. Site layout

The monitoring site is a square shape of 25 metres by 25 metres (total area of 625 m^2). The selection of this shape and size is arbitrary but McKenzie *et al*. (2002b) provides the reasons as to why this size and shape is appropriate for the National Soil Condition Monitoring Program.

Perimeter layout

The Monitoring Site is a square shape of 25 by 25 metres (625 m^2). Following are guidelines for establishing the site area:

- The pre-determined coordinates are used to locate the south west corner of the Monitoring Site.

- From the south west corner the sides of the square are established to align with magnetic North-South and East-West. This can be done using an accurate sighting compass. The line from the south west corner to the south east corner (southern line) forms the baseline.
- The 4 corners are marked with posts and should be visible above the vegetation to define the locations for the photographs of the site.
- Using two 50 m reel tapes mark out the perimeter, with one reel tape measuring 25 m from the south west to north west corner and then at right angles to the adjacent north east corner. The layout is a square, therefore two sides of the square form a right angle of a triangle with the diagonal measuring a distance of 35.36 m ($25^2 + 25^2 = 35.36^2$). Therefore, at the same time use a second reel tape to form the diagonal of a right angled triangle from the south west corner to the north east corner to assist with keeping the square at right angles by intersecting the first tape (at 50 m) to locate the corner. A third reel tape can then be used to mark the other two sides.

If a square shape or a north-south and east-west orientation is not suitable.

In some circumstances the shape and orientation may need to be different. If this is necessary, the dimensions should be adjusted to maintain a total area of 625 m^2 and the orientation of the shape should be recorded.

Internal Layout

There are a number of ways to generate an internal layout (and various monitoring programs in place have already established their systems). The requirements for the National Soil Condition Monitoring Program are:

1. the 10 sampling locations are to be determined randomly and
2. the sampling location positions are accurately noted (in terms of distance from the origin at the south-west corner, in metres east and metres north) so that subsequent sampling events can exclude those locations.

The recommended internal layout uses a Latin Square design approach where each row or column is sampled only once in each sampling event. A randomised approach is used to select the sample location and to remove judgement bias. The following guidelines for establishing the internal layout and selecting sample locations are:

- A 10 by 10 grid.
- The south west corner is defined as the origin.
- Grid lines at 2.5 m intervals in the north and east direction from the origin point.
- The north south grid lines are numbered as columns 1 through to 10, and the east west grid lines are numbered as rows A to J. The 0 metre lines are not used for sampling as these line areas will become disturbed during site layout and particularly near the origin point (0 by 0 metres) that is used for the staging area and digging of the characterisation pit. The layout is shown in Figure 4-1.
- Sample locations are at the grid intersection representing a potential of 100 points.
- For each sampling event one grid intersection per column and row is selected. This is determined by randomly sorting the rows (A to J) and then allocating from first to last with each column (1 to 10).

- It is important that the sample location is not moved subjectively from the grid intersection to “avoid” a feature such as bare ground or rock or something else. Sampling is to occur at the pre-determined grid intersection position.
- This allocation will have no redundancy in the first sampling event. For subsequent sampling events if a randomly selected row for a column has previously been sampled (and therefore removed from the potential sampling population) then the next closest adjacent row is used for that column. A randomised table that could be used for sample locations by event, column and row is provided in Appendix 4. An example showing the distribution for the first four sampling events is shown in Figure 4-2.
- As well as recording the column and row position the distance are to be recorded to the nearest tenth of a metre. The origin is the south west corner with the easting number first and the northing number second. Recording the site positions in this way provides flexibility to record the sample location position allowing the location to be plotted.

If the above grid layout approach is not used

The above internal grid layout for selecting 10 sample locations is the recommended approach. For various reasons alternative layouts have and may be used. If alternative layout methods are used then the sample location positions must be selected randomly and their location accurately recorded so that subsequent sampling events do not occur at the same sample position. The sample positions are recorded as metres east and north, providing an internal grid reference in metres.

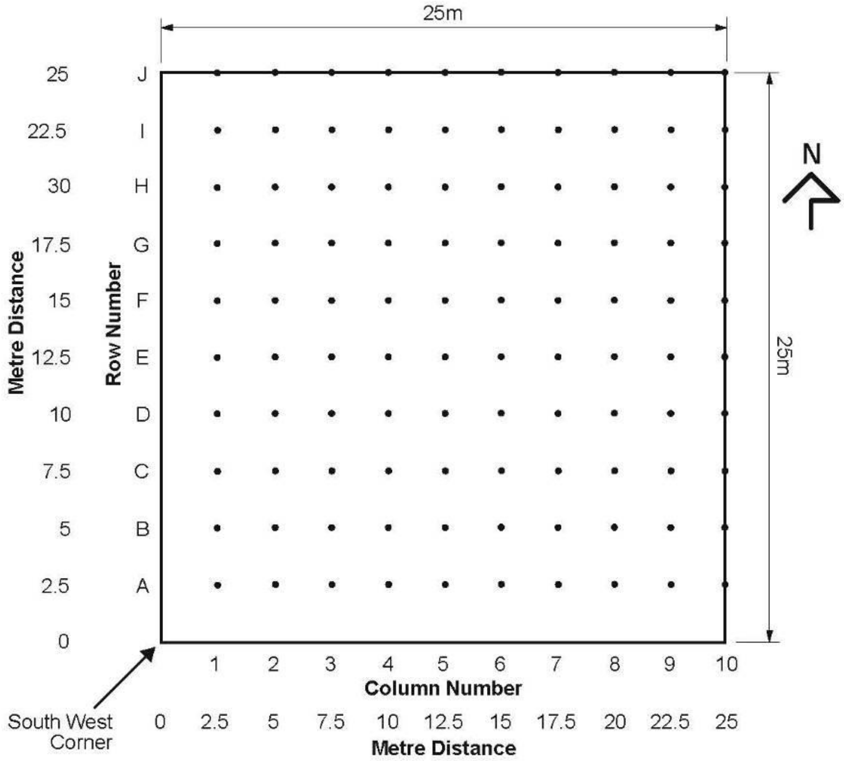


Figure 4-1. Sample gird layout for the Monitoring Site. The points marked on the grid indicate candidate sampling locations.

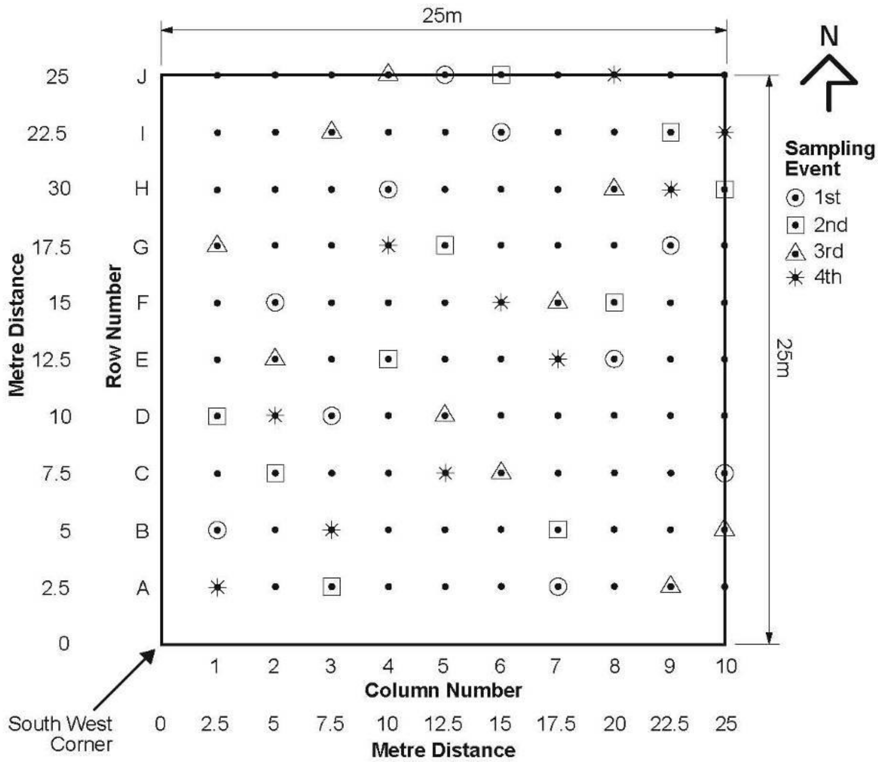


Figure 4-2. Monitoring Site grid layout and showing the candidate sampling positions for the first 4 sampling events.

4.2.5. Site location and marker

Site location

Once the site has been located and laid out, a differential global position system (DGPS) unit should be used to acquire an accurate position of the south-west corner coordinates. This DGPS reading will be used to place the site spatially and more importantly used to relocate the site in the future. It is essential that an accurate (less than ± 1 m) reading is obtained.

Marker

The National Soil Condition Monitoring Program ***does not*** require a marker to be placed in the soil or on surrounding structures to assist with future identification of the site position. An accurate coordinate position obtained by a differential global position system unit with sub-metre accuracy should provide sufficient information to allow the site to be relocated.

Jurisdictions at their discretion may find it useful to place markers that could be used to backup and confirm the site location in the future. This may be a buried object (such as a metal lump or passive transponder) placed at a site corner or reflective markers fixed to structures (such as fence posts or trees) with a distance and direction to the site corner. The utility and effectiveness of these backup markers should be tested for the soil type and land use, as anecdotal information indicates that they are very difficult to relocate and use. If a marker is to be buried or fixed to surrounding structures then landowner permission is required. The location of the buried marker should be described on field notes that identify the site corner it is buried at and/or what structures markers are attached to in relation to the site corners.

4.2.6. Photographs

Photographs are to be taken of various features relevant to the Monitoring Site.

Requirements of the photographs taken include:

- Digital
- Generates photographs of at least 600 dpi (specific optic quality required)
- JPEG format
- Camera set so that correct Date and Time properties are associated with the digital photograph
- File name convention consists of "project identifier code, site number, date, sequential photograph number, file format" as shown in Table 4-3.
- Original photographs should be stored.
- If an original photograph has been copied and then modified by cropping, enhancements, or compression then this file is identified by using same as the original file name and a suffix ("_mod") to indicate a modification.

The required minimum set of photographs to be taken at each site includes:

- Project and site number, co-ordinates, and date. This should be the first photograph in the sequence for the site photographs and can be obtained by photographing the information that has been written either in the field recording sheet, log book, marker board or on paper.
- Site photographs, four photographs to be taken one from each of the four corners. Standing at each corner of the site, take a photograph into the site area and include in the field of view of the photograph as many of the other 3 corner markers as

possible (identified preferably by the marker poles, otherwise people standing at the corner or some other easily recognisable object).

- Soil surface photograph. A vertical photograph from a height of about 1 m that shows the surface features and ground cover, a scale marker must be included in the photograph.
- Soil profile. A photograph of the soil profile, with a scale tape placed to one side of the soil profile, and the photograph taken at an angle as horizontal as possible.
- Any other features of interest. As determined by the sampling team.

Table 4-3. Photograph file name convention protocols, example for photograph TBD_003_20100817-02.JPG (or TBD_003_20100817-02MOD.JPG).

Component	Purpose	Example	Template and allowed values
Project Identifier Code	Project identifier code that uniquely identifies the project.	TBD	Alphanumeric characters.
Site number	Unique number that identifies the site within the project area. This number and the project identifier code can be associated with the database of information collected for the Monitoring Site.	_003	An underscore to separate, followed by three numbers.
Date	Places photograph date in the file name.	_20100817	An underscore to separate, followed by 8 digit date as year, month, day
Photograph number	Starting at one, a consecutive number sequence associated with each photograph taken for the site. The first photograph is of the site number, coordinates and date. Photographs can be placed in any order.	_02	An underscore to separate, followed by two digit number.
Modification	Identifies a copy of an original photograph that has been modified (cropping, enhancements or reduced), by using the same original photograph file name with an additional suffix that indicates modifications.	_mod	Only include if photograph has been modified.
File extension separator	Separates the name from the file type extension	.	A full-stop.
File type	Identifies the file format type	jpg	Letters to indicate the file format such as ‘jpg’

4.3. Soil sampling of the Monitoring Site

4.3.1. Location of the soil sample position

The internal layout of the Monitoring Site is described in Section 4.2.4 which identifies the positions for collecting the individual soil samples.

The sample position is at the randomly selected grid intersections points and is not to be relocated or substituted. This removes the need for judgement decisions to be made as to where the sample location should be placed such as may occur if there is ridge and furrow topography or variable surface micro-topography or within / between planted rows. The sample location is defined as the grid intersects position.

4.3.2. Soil sample layer depths

Soil samples at each soil sample position will be extracted at 3 depths from the soil surface where soil mineral grains are encountered (surface depth = 0 cm). The samples are to be collected as a stack, which is each sample depth is collected from the same position and therefore is directly below the sample previously collected from above. The sample depths are:

- 0 to 10 cm,
- 10 to 20 cm,
- 20 to 30 cm.

For subsequent sampling events a 4th depth (30 to 40 cm) may be required if the bulk density in the 0 to 30 cm depth has decreased from the original sampling event to allow standardisation to same mass.

4.3.3. Problems with soil sample recovery

Soil sample recovery may be a problem when there are too many coarse fragments, rock outcrop, large roots, vegetation cover, shallow covered bedrock, or soil conditions that are too dry or too wet.

When this occurs the sampling location within the monitoring site is ***not relocated or substituted***, the collection of that sample is abandoned. When sampling at a position or a sampling depth is abandoned, a notation is made on the field sheet as to why the sample was not collected and the sample bag is marked up with 'no sample collected'.

It is essential that abandoned sample positions or sample layer is clearly noted as the calculations made will need to be adjusted.

Examples of soil sample recovery problems and actions to take:

Vegetation at the sample position – vegetation such as grass or crop stubble is at the sample position. Vegetation should be cut with sharp knife or similar down to the mineral surface to allow sample cores to be placed into the soil surface and enable an accurate volume of soil to be collected.

Tree is located at the sample position – no soil can be recovered at any of the sample depth intervals. Collections of the samples for that sample position are abandoned, mark the field sheet and sample bags to describe this.

Stone in the entire sample layer – abandon collecting a soil sample for this layer and mark the field sheet and layer sample bag to describe this. If it is possible to remove the stone, continue collecting soil samples for the remaining soil sample layers.

Bedrock – sample the upper soil interval to the depth of where the bedrock is encountered. For the layers where soil sample cannot be obtained due to the bedrock, abandon collecting a soil sample for this layer or layers and mark the field sheet and layer sample bag to describe this.

Gravel or plant roots in soil layers – collection of the soil sample for a layer is limited by gravel or plant roots restricting extraction and compromising the sample quality. If possible continue to collect the sample and make a notation on the field sheet that the sample was compromised and what impact this may have.

Irregular surface micro-topography due to raised beds, cultivation (such as seeding lines), and gilgai – the sample locations within the internal grid are specified by the randomly selected grid intersection points, this is where the sample is to be collected from and no adjustment or relocation is required. The location may fall anywhere along the surface micro-topography from the crest top to the bottom of a furrow.

Repeating orientation of the surface micro-topography or/and where the pattern is orientated according to the grid lines – there is no requirement to offset the grid origin or establish the grid at a different angle. The grid origin is to remain as the pre-defined Monitoring Site co-ordinate and the Sample Site layout is to remain as described above with the north-south and east-west orientation.

Void areas such as open cracks in a Vertosol – if the gird intersection position for a sample site location falls at a void area then no sample is collected and mark the field sheet and layer sample bag to describe this. The sample location is not replaced with another sample location.

Controlled traffic wheel tracks or irrigation channels – where a sample site occurs on these areas or similar that are clearly not part of the land use and management that is being monitored then this is documented as the sample data cannot be used.

4.3.4. Sample collection

The minimum guidelines for soil sample collection are:

- The volume of soil collected from each sample location and depth interval is to be the same.
- The sample collected is to be from the entire depth range for that sampled layer. Each sample collected will be the same volume for that sampled depth.
- To extract soil samples it is recommended that a coring tube is used which is 50 mm in diameter. Preferably the core should be pushed in using a vehicle mounted coring rig to allow the core to be smoothly pushed into the soil and extracted, as shown in Figure 4-3. An alternative is to drive the coring tube into the soil using a hammer as shown in Figure 4-4.
- The soil surface (or zero depth) is considered where the mineral soil starts. It is does not include grass thatching or a litter layer.
- The outside of the coring tube should be marked with the sample depth intervals. Each sample interval should be cored and extracted separately as this allows an accurate sample volume to be collected and reduces the impact of compression, and the three sample depth intervals stacked at the one sample position (use the same sample hole and collect for each depth interval). Care needs to be taken to ensure that the entire depth interval has been extracted and that soil material does not fall into the hole prior to the lower sample being collected. In some cases the entire 30 cm interval will need to be collected as one core, the sample extruded out and divided into the three sample depth intervals. Care needs to be exercised, taking into account soil compression and dividing the soil core at the correct depth increments.

- Measure the depth to the soil surface both inside and outside the soil tube before extraction of core to assess potential soil compaction within the extracted soil core.
- Collecting soil samples in this way allows a sufficient volume of soil to be collected for chemical analysis and when collected carefully allows a bulk density measurement to be obtained for each sample collected.
- This sample core method is effective in moist soils, but when the soils are hard, loose or dry then alternative methods for extracting the sample will be required. The soil spear is effective particularly in dry sand textured soils, but because of the small diameter (about 10 mm) multiple extractions of the soil at the sample location position may be required to obtain sufficient volume of soil (Figure 4-5). Where these tools do not work, then a shovel will need to be used to create a small pit to extract the soil. Bulk density cannot be calculated from these samples and a separate bulk density sampling effort will need to be conducted.
- If coarse fragments (fragments >2 mm) are a part of the soil horizon it is important that the sampling method recovers a proportional amount of these fragments in the sample bag.
- The sample collected is to be from the entire depth range for that sampled layer.
- All samples are to be collected in such a way to avoid cross-contamination of the sample – requiring careful extraction of sample, clean sampling tools and clean sample containers.

Collecting samples as individuals

- The soil from each of the sampled layers is to be placed into separate plastic bags and sealed. The bag should be marked with the date; site number, plot grid position, and sample depth range. If no soil is recovered for a soil layer then the bag is marked up and a notation made on it that 'no sample recovered'.
- Insert a durable label inside each bag with sample in case external markings are obscured. These can be pre-printed prior to field work.
- The three sample bags for a soil sample position are gathered into one larger bag which is marked with date, site number and plot grid coordinates.
- The amount of sample to collect is a minimum of 500 grams of dry weight for the fine earth (<2 mm fraction). Where the soil contains coarse fragments then the weight of soil collected in the field needs greater to allow for collection of sufficient soil in the fine earth fraction, it may be necessary to collect two cores..
- For the first sample event of the project, soil samples from different soil sample positions will be collected and bagged separately for analysis. As the project progresses and data is analysed there should be a shift to bulking of soil samples at a site to improve efficiencies and reduce the cost of analysis. The bulked sample can provide an estimate only of the mean, and not of the variance, therefore it is important in the earlier stages of the project to obtain replicate samples within the monitoring site to determine the variance.

Collecting samples and bulking

The bulking of soil samples in the initial phases of the project will not occur as individual samples are required to calculate the soil variance. As the Program progresses and bulking becomes appropriate then:

- The bulked samples must be from the same depth layer and occur within the same Monitoring Site.

- Each individual sample contributing to the bulk sample must be of the same volume.
- Bulking of the sample is to be done either in the field when the samples are collected or at a later stage but must be done before the samples are dried, ground and sieved. This is necessary to ensure that the individual samples are treated equally.

Figure 4-3. Coring tube being pushed into the soil to the required depth using a vehicle mounted rig.

Figure 4-4. A coring tube of 50 mm diameter used to obtain soil samples and allow bulk density to be determined from the same sample. The outside of the tube is marked to indicate the different sample collection depths. A wooden mallet or wood block and hammer are used to drive the tube into the soil.

Figure 4-5. A soil spear used to obtain soil samples is hammered 30 cm into the ground to obtain a continuous soil core.

The outside of the tube is marked to indicate the different sample collection depths and these are systematically extracted into the sample collection container. It may be necessary to extract more than one core from each sample location to obtain sufficient soil volume. Note: a separate bulk density sampling using cores at selected locations will be required with this soil collection approach.

4.3.5. Bulk density sample collection

A bulk density measurement for each soil layer is required:

- to allow weighed measurements to be converted to volume, and
- to identify changes in bulk density over time this can mask or confuse real trends in soil parameters. With the bulk density known, soil organic carbon content can be adjusted to a soil mass equivalent.

The bulk density method is essentially that described as the Intact Core Method (Method 503.01) in Chapter 3 Bulk Density and Pore Relations by Cresswell HP and Hamilton GJ in "Soil physical measurement and interpretation for land evaluation" McKenzie NJ, Coughlan KJ and Cresswell HP, (2002), see Appendix 1.

The bulk density core can be obtained from either of the following means:

1. The preferred approach is that the bulk density soil core is the same soil core used to for chemical analysis. For this approach the soil coring tube needs to have a diameter of about 50 mm or larger and the length of the soil core is the same as the sample depth range which is 100 mm. Following this approach means that the bulk density data is directly related to the soil that is chemically analysed, if there is confidence that the required volume collected by the coring tube is correct then there is no need to conduct a separate bulk density sampling exercise, thus allowing the one collected soil core to serve two purposes – sample for chemical analysis and sample to determine bulk density.
2. In some circumstances, collecting soil using the cores can prove difficult if the soil is not at an optimal condition (such as when the soil is either dry, hard, sandy, or contains coarse fragments). If the soil samples are not collected using a large diameter coring tube or there is uncertainty about proper recover of the required soil volume then a separate bulk density sampling exercise will be carried out as outlined here. The minimum guidelines for collection of bulk density samples separate from the soil sample for chemical analysis are:
   - Four soil sample positions will be cored for bulk density. They will be located adjacent to the soil sample locations that are closest to the four perimeter corner markers.
   - Two bulk density cores will be collected for each of the soil sample depth increments at each of the four positions.
   - Samples are to be collected separately and processed.
3. Diameter of the coring ring or tube is to be measured, using Vernier or digital callipers. Replicated measurements should be taken at a minimum of five positions and averaged.
4. Issue of bulk density in vertic soils.
   - Sample for bulk density when soil is as close as possible to field capacity (or pre-wet the site)
   - Gravimetric moisture content of the wet soil (as sampled) should be determined. Therefore bulk density measurements obtained at different times can be compared in terms of their respective moisture contents. If sampled 'wet' bulk density can be estimated from appropriate pedo-transfer function.

4.4. Site and soil characterisation

The purpose of the site and soil profile characterization (McKenzie *et al.* 2002) provides:

- A basis for extrapolating results to other similar soils (including sufficient information to assess the relationship with soil or landscape units).
- A means for grouping or stratifying sites to aid measurement and analysis.
- Insights into anomalous or unusual results.

The outputs include:

- Locating the monitoring site within the landscape.
- Identification of soil horizons and their depths.
- Description of the soil horizon features.
- Collection of soil samples from each soil horizon for laboratory analysis to determine necessary soil properties to characterise the soil (note this is different sampling to that conducted for the monitoring samples).
- Classification of the soil profile according to the Australian Soil Classification (Isbell 2002) and to the local soil name or mapping unit (if there is one).
- Photograph of the soil profile

The site and soil profile characterization will be conducted during the first sampling event. It does not need to be conducted for subsequent sampling events unless there is a reason or need.

4.4.1. Location of soil profile description

A soil profile description is to be made and located adjacent to the south-west corner of the monitoring site and just outside of the site perimeter boundary.

Digging of a soil pit is required to facilitate taking of a quality soil profile photographs. It is expected that it would be to a depth of at least 30 cm and preferably 50 cm or more. The deeper layers can be described from an auger boring or core to a depth of at least 1 metre or deeper if necessary to classify the soil profile.

The soil profile description and collection of samples for soil characterisation can be made from either a soil core or from the soil pit, the extraction and description of the soil should be according to your Jurisdiction guidelines for soil characterisations and soil classification. The soil profile should be described to a depth of at least 1 m (or less than 1 m if the soil is shallow overlying bedrock or an impenetrable layer), or deeper if information is required to confirm the soil classification or it is feasible to obtain soil information.

4.4.2. Description and photograph

The soil profile is to be described according the 'Australian soil and land survey field handbook' (NCST 2009). A complete description of the site and soil is required, and guidance on the data set to collect for the soil type is determined by the jurisdiction agency conducting the work following their protocols to meet their profile description data sets requirements.

The minimum data set that is to be collected for the National Soil Condition Monitoring Program is specified in Table 4-4, and a more detailed description can be made if required and resources are available. The soil is to be described and sampled by horizon, not by standard regular depth increments.

The chemical and physical properties to be measured are to provide an indication of at least soil nutrient availability, limitation to root growth, and the soil water regime and the taxonomic class of the soil. Ideally all monitoring site profiles should undergo chemical and physical analysis but this will not be feasible, therefore a minimum of 5% of profiles from a Monitoring Unit should have samples analysed for key properties relevant to that soil type.

The soil photograph should be taken with a scale tape placed to one side of the soil profile, and the photograph taken at a horizontal an angle as possible. The soil face for photographing should be prepared according to best-practice and any guidelines specified by your agency.

Table 4-4. List of variables for the site and soil profile characterization to provide the minimum data set.

Variable	Method
Identification and Location	
Date	Year, month, day
Site number and project number	Specified by project
Coordinates (easting, northing, zone)	Metres, GDA94, UTM (MGA)
Taxonomic soil class	Great Group level of the Australian Soil Classification (Isbell 2002)
Local soil name	If there is one and the reference
Soil map unit	Name and reference
Photographs (profile, site, surface)	Profile photograph to have a scale tape and taken at a horizontal angle, for materials extracted below the pit base photograph the layer piles or core. Site photograph include the soil pit in foreground with the dominant land use in the background. Surface photograph include a scale tape and take as vertical as possible at about 1m height.
Site	
Lithology	Table 35 (NCST 2009)
Substrate	Table 37 (NCST 2009)
Landform element (slope class, morphological type)	Pages 17 to 26 (NCST 2009)
Landform pattern (relief, modal slope)	Pages 44 to 47 (NCST 2009)
Land surface (aspect, slope angle, coarse fragments (abundance, size, lithology))	Pages 127 to 145 (NCST 2009)
Vegetation structural formation	Pages 88 to 93 (NCST 2009)
Floristic	Pages 95 to 101 (NCST 2009)
Land use	BRS 2002

Soil Morphology	
Horizons (designation)	Pages 148 to 156 (NCST 2009)
Depth of Horizons (upper and lower depths)	Pages 156 to 159 (NCST 2009)
Colour (matrix and mottles)	Pages 159 to 161 (NCST 2009)
Field texture	Pages 161 to 170 (NCST 2009)
Coarse fragments (abundance, size, lithology)	Pages 170 to 171 (NCST 2009)
Structure (grade, size, type)	Pages 171 to 181 (NCST 2009)
Consistence (strength)	Pages 186 to 187 (NCST 2009)
Segregation of pedogenic origin (abundance, nature)	Pages 195 to 196 (NCST 2009)
Chemical Properties*	(Sufficient for allocation to the Great Group level of the Australian Soil Classification)
pH in $CaCl_2$ and water (1:5)	Method code
Organic carbon	Method code
Exchangeable cations	Method code
Cation exchange capacity	Method code
Electrical conductivity	Method code
Physical Properties*	(Sufficient for interpretation of the soil-water regime and root growth)
Particle size distribution	Method code
Bulk density	Method code
Water retention	Method code
Hydraulic conductivity	Method code
Aggregate stability	Method code

* Chemical and physical properties listed are a guide with the intention to provide an indication of at least soil nutrient availability, limitations to root growth, the soil water regime and the taxonomic class of the soil. A judgement will be required to be made as to the actual tests conducted.

4.4.3. Soil sampling of pit for profile characterisation

Sampling depth intervals

Bulk soil samples for characterisation analysis are to be collected. The depth sample and description intervals should be according to the Jurisdiction soil sampling protocols as these are expected to be tailored for the type of soils that are encountered. Alternatively, it is anticipated that sampling would be by soil horizons.

Volume of soil to be collected

The amount of soil to be collected for each horizon should be determined in consultation with the laboratory conducting the analysis. Sufficient sample should be collected for routine analysis and for archived storage. It is expected that the bulk soil will be about 1.5 to 2.0 kg of material, and if coarse fragments (>2 mm) are present then a larger sample is required, as the proportion of these samples will be determined by sieving the soil after grinding and will reduce the bulk volume of <2 mm soil for analysis.

Guidelines for collecting soil samples are provided in Rayment and Higginson 1992 (Chapter 1 of the Australian laboratory handbook of soil and water chemical methods).

Laboratory analyses

The laboratory analyses to be conducted for the National Soil Condition Monitoring Program are listed in Table 4-4. Additional analyses can be added at the jurisdictions discretion if funds are available to conduct the work. Laboratory analyses for soil profile characterisation samples will be managed by the jurisdiction at the laboratory facilities that they would normally use to obtain analytical soil characterisation data.

4.5. Sample handling and transport

The following points are guidelines for soil sample handling:

- Soil samples are to be collected in clean standard plastic sample bags or jars.
- Sample bags are to be clearly marked with collection date, site identification number, and site grid location position and sample depth range. This can be done with permanent marker pen or stick on labels. An internal label is recommended.
- All sample bags and containers are to be clean on the outside to minimise contamination during transportation and on receipt at the laboratory.
- Seal bags for moisture and remove air pockets to prevent bags bursting.
- Samples are to be kept cool and preferably below the ambient temperature when transported and stored.
- Samples are to be delivered to the laboratory as soon as practical, and before a maximum of 14 days have elapsed.
- Samples collected from the monitoring site are to be delivered to the central project laboratory – NAME and ADDRESS to be determined.
- Samples collected from the site characterisation profile are the responsibility of the jurisdiction and are to be processed according to their requirements and laboratory.
- A sample delivery list (chain of custody form) should be emailed to the laboratory and also provided in hardcopy with the sample shipment.

4.6. Land management record

Information on land management is critical for interpreting the results of monitoring.

The minimum data set of information to collect follows that used for the SCaRP program. An example questionnaire for the Landowner to complete is presented in Appendix 5. This questionnaire should satisfy most of the land uses that are to be monitored. If necessary additional codes can be added to the question fields to accommodate other land uses.

4.7. Laboratory Analysis

Laboratory analysis will be controlled by one laboratory facility, the Central Soil Analytical Laboratory, to ensure the same methods and processes are used. The Central Soil Analytical Laboratory will be NATA (National Authority of Testing Laboratories, Australia) and ASPAC (Australasian Soil and Plant Council) compliant and will have the capability and capacity to conduct all required analyses, including maintaining the quality control and quality assurance required.

Jurisdictions may wish to use an alternative laboratory. This is possible but must be agreed to by the National Team who will take advise from the Central Soil Analytical Laboratory that will confirm if the alternative laboratory can satisfy the work and quality requirements. The alternative laboratory must be an established facility that will endure throughout the monitoring program. All samples from a Monitoring Unit must be analysed at the same laboratory. Work conducted by the alternative laboratory must follow the methods specified and include standard samples to monitor consistence, and allow the Central Soil Analytical Laboratory to conduct reviews of data and operations and if necessary reanalysis of samples.

The organisation and facility to have the role as Central Soil Analytical Laboratory is to be determined.

4.7.1. Soil preparation

Soil samples are to be prepared in accordance with the Australian Standard 'AS 4433.2-1997 Guide to the sampling of particulate materials – preparation of samples'. The general approach to meet the needs of the soil organic carbon and pH include the following:

- Air-dry the soil sample to constant mass (alternatively 40°C for at least 48 hours).
- Screen though a 2 mm sieve – to separate fine earth fraction from coarse fraction.
- Recover coarse organic matter (>2 mm), weigh and set the organic material aside for processing.
- The remaining >2 mm is progressively crushed to break up aggregates of soil primary particles by using an automated crushing device. The coarse fragments (>2 mm material) are removed dried and weighted.
- Weigh the <2 mm material.
- Thoroughly mix <2 mm material by passing through a riffle splitter 5 times, returning all to the hopper on each pass.
- Riffle split to segregate sample for moisture content and sample split for analysis.

4.7.2. Bulk density analysis

The method for the bulk density analysis is essentially that of the Intact Core Method (Method 503.01) that is presented in Chapter 3 Bulk Density and Pore Relations by Cresswell HP and Hamilton GJ in "Soil physical measurement and interpretation for land evaluation" McKenzie NJ, Coughlan KJ and Cresswell HP, 2002, CSIRO. The description of the method is presented in Appendix 1.

4.7.3. Soil organic carbon analysis

The rationale and method for soil organic carbon analysis was presented in Baldock *et al.* (2010). The descriptions of these methods are presented without alteration as Appendix 2. All samples will be analysed to determine total carbon (Method 2.1) and fractionation of soil organic carbon by indirect measurement by mid-infrared spectroscopy (Method 2.4), a subset of samples will be analysed by Methods 2.3 and 2.5 and Method 2.2 when required as outlined in Table 4-5.

Table 4-5. List of methods for soil organic carbon analyses and indication of samples to be analysed by each of the methods.

Method Number	Method Name	Samples Analysed	Comment
2.1	Total carbon analysis	All	Provides key value
2.2	Sample pre-treatment to remove carbonate carbon	When required	Conducted prior to total carbon analysis
2.3	Fractionation of soil organic carbon – direct measurement	Subset of samples from each Monitoring Unit	Provides quantitative data for calibration of the indirect measurement Method 2.4
2.4	Fractionation of soil organic carbon – indirect measurement by mid infrared spectroscopy	All	Provides a rapid and less expensive means of generating estimates
2.5	Determination of mineralisable C and N	Subset of samples when required	

4.7.4. Soil pH analysis

The rationale and method for soil pH analysis was presented in Baldock *et al.* (2010). The descriptions of these methods are presented without alteration as Appendix 3. All samples will be analysed to determine Soil pH in Calcium Chloride (Method 3.1) and pH buffering capacity by Mehlich buffer method (Method 3.2), a subset of samples will undergo Method 3.3, and Methods 3.4, 3.5 and 3.6 are calculations preformed on the data obtained as outlined in Table 4-6.

Table 4-6. List of methods for pH analyses and indication of samples to be analysed by each of the methods.

Method Number	Method Name	Samples Analysed	Comment
3.1	Soil pH in Calcium Chloride	All	Provides key value
3.2	pH buffering capacity by Mehlich buffer method	All	Provides a rapid and less expensive means of generating estimates
3.3	pH buffering capacity by titration	Subset of samples from each Monitoring Unit	Provide quantitative data for calibration of the rapid measurement Method 3.2
3.4	Lime requirement for liming to critical pH	All	Calculation

3.5	Estimating NAAR by ΔpH and pHBC	All	Calculation
3.6	Estimating NAAR by carbon and nitrogen cycles		

4.8. Repeat sampling in the future

4.8.1. Return time

This monitoring program has been designed to allow repeated sampling of all Monitoring Sites into the foreseeable future on a 5 year cycle.

For repeat sampling the exact Monitoring Site location is to be revisited. The soil sampling conducted for the monitoring is destructive therefore a slightly different set of soil sampling location positions are to be used, to minimise the possibility of collecting sample from a previously sampled location where the core or pit hole has been refilled.

The exact south west corner should be located using the coordinates, then the same perimeter and internal site layout is to be established.

4.8.2. Exhaustion and replacement of Monitoring Sites

It is probably that some Monitoring Sites over time will no longer be suitable and will need to be abandoned. Reasons to abandon the Monitoring Site include:

- The land use has changed significantly, so that it no longer fits within the defined Monitoring Unit concept. The exception to this is if the change in land use is representative of a general shift in land use and if so these sites will be retained to represent the evolution of the Monitoring Unit occurring through time, as this happens the Monitoring Unit concept will be updated.
- Change in Landowner cooperation to allow access. If support of the Landowner is not given to allow access to the property, then the site will be abandoned.
- A change in the management of the land use (in addition to the normal land management practice) implemented only because the Landowner is aware the site location is part of the Monitoring Program, presumably to effect an improvement in the soil health at the site different to what would normally occur. This would be difficult to determine but if identified then the Monitoring Site will be abandoned.
- The site is “too disturbed” by previous sampling or other actions over the area. Sampling is destructive therefore a time will be reached when there is insufficient area remaining to be sampled to be certain that it is representative, if this is identified then the Monitoring Site will be abandoned. Given the very small footprint area disturbed for collecting multiple samples at a time estimated to be no more than 1% of the total area for each sampling event, it is unlikely that this will be an issue until many sampling events have been conducted.

Abandoning sites will impact on the full set of sites required to support the statistical analysis for the future monitoring. It is likely that over time sites will be abandoned and to compensate for this attrition additional sites will be required. This can be done by:

- Including additional sites into the initial establishment of the program so that there is excess Monitoring Sites for the Monitoring Unit, and/or
- For each Monitoring Site abandoned a new one is added by selecting the next site on the list.

5. REPORTING, DATA MANAGEMENT AND SAMPLE ARCHIVING

It is important that all data is analysed and reported in a similar way to allow comparisons within and between different sites, units, regions and for a National assessment.

5.1. Reporting

Interpretation of data and generating the reports will be conducted by the Jurisdiction that conducted the work.

5.1.1. Report structure

The reporting of the Monitoring Unit data and findings will follow a standardised structure. The intent is to summarise information for each Monitoring Unit into three pages, with page one describing the Monitoring Unit, page two providing data results, and page three a summary of key findings. An example of the standard report pages and the information that is required to be included is presented in Appendix 6.

5.2. Data Management

The National Soil Condition Monitoring Program will collect a large quantity of data over a long-term period, potentially covering many decades. The success of the Program, other uses of the information and retention of the data relies on the individuals and agencies maintaining interest in and continuity of the data collected.

All data will be collated and stored at a central location within the Australian Soil Resource Information System (ASRIS) and managed by CSIRO on behalf of the Australian Collaborative Land Evaluation Program (ACLEP see http://www.clw.csiro.au/aclep/).

5.2.1. Original data sheets

The original data sheets will consist of three forms for each Monitoring Site i) site and profile characterisation description sheet, ii) the monitoring sample location recording sheet, and iii) the farm management questionnaire. A scanned copy of each of these sheets will be electronically included as part of the ASRIS central data management. They will be cross-referenced with the monitoring data and maintained in the National Soil (NatSoil) database.

The hardcopies are retained by the jurisdiction conducting the work for a minimum of 10 years (after two subsequent sampling events have been reported) and preferably longer.

5.2.2. Database

Data will be compiled and delivered by the Jurisdiction collecting the information, and they will check and verify their field and laboratory data prior to forwarding it to the managers of the ASRIS NatSoil database. To facilitate efficient delivery and upload and ensure standards are maintained, users will compile data into an appropriate data base or other file format. The NatSoil specifications documentation will identify the required data fields and provides a standard structure.

5.2.3. Photograph library

The digital photographs named according to the file format in Table 4-3 will be electronically included as part of the ASRIS central data management. They will be cross-referenced with the monitoring data and maintained in the NatSoil database.

5.3. Soil Sample Archive

Sample archiving is essential to the long term value of the monitoring system and has potential value beyond the immediate aims of the project.

5.3.1. Storage location and storage standards

All samples collected as part of the National Soil Condition Monitoring program will be archived at the CSIRO National Soil Archive, Black Mountain Laboratories in Canberra.

Samples will be stored according to the standards established for the CSIRO National Soil Archive (see http://www.clw.csiro.au/aclep/archive/index.htm#archive_submission).

All archived soil samples will be cross-referenced with the monitoring data in the ASRIS NatSoil database.

The National Soil Archive currently does not split samples and store them elsewhere to serve as a backup in the event the National Soil Archive is damaged or destroyed.

Where the jurisdiction maintains a soil archive, they can retain a duplicate sample to be held in their archive for the soil samples that they have collected.

5.3.2. Release of sample for further study

Requests for other uses of sample are to be made to the National Coordinator who will provide authorisation for release to the manager of the CSIRO National Soil Archive who will arrange access as per standard National Soil Archive conditions (see http://www.clw.csiro.au/aclep/archive/index.htm#archive_use).

A log of sample release is to be kept that includes i) date, ii) who and iii) what the sample use will be. This is cross-referenced back to the NatSoil database.

6. QUALITY ASSURANCE / QUALITY CONTROL

Strict adherence to Quality Assurance and Quality Control procedures shall occur at all stages of the work to ensure scientific integrity of the data and results.

Quality Assurance and Quality Control procedures should be documented for:

- Program direction and management
- Data collection
- Data interpretation and reporting

6.1. Program direction and management

The program direction and management will be reviewed annually by the Oversight Committee to ensure that the Program maintains a focus on the required goals and outputs. At least once every 5 years the Oversight Committee will engage an independent review of the Program. The Oversight Committee is responsible to take action and implement change if required.

6.2. Data collection

The Jurisdictions are responsible for quality of the data and work conducted. The National Coordinator and the technical support team will conduct oversight of all data and work to ensure national standards are met and they will work with the Jurisdictions to check and verify data collected.

6.2.1. Site selection and sample collection

Appropriate site selection and sample collection from the correct soil layers is critical. Collected samples that are not representative will waste valuable resources on subsequent laboratory analysis and data interpretation, and produce invalid information for assessment in the monitoring program.

All site locations and the sampled layers shall be identified and selected by a Senior Soil Surveyor or a person equivalently skilled, using best practice principles.

In the report section for Quality Assurance and Quality Control, a statement will be included that identifies the Senior Soil Surveyor, when they were at the study area, what they did to select the site locations and the layers to be sampled, any issues of concern and the actions taken.

At the discretion of the National Coordinator, an observer may be used to review the field procedures being carried out, provide feedback to the Surveyors on their approach and report back to the National Coordinator and Jurisdiction Team Leader, including a letter report on the review findings.

6.2.2. Laboratory analysis

Laboratory analyses will be conducted at recognised laboratories that are NATA (National Association of Testing Authorities) accredited for the particular parameters and methods required. For analyses that are not NATA accredited, then at recognised laboratories that maintain appropriate standards that satisfy the National Coordinator and technical support team. For all tests and analyses, the Quality Assurance and Quality Control procedures will be equivalent to those endorsed by NATA and ASPAC.

All data prior to being released will undergo checks and be signed off by the Laboratory Quality Assurance / Quality Control manager. The laboratory report should be a NATA endorsed report or equivalent standard.

In the report section for Quality Assurance and Quality Control a statement will be included that provides a summary of quality control results, any issues arising and where the QA/QC data is held should a review be necessary.

At the discretion of the client, the laboratory may be requested to provide all QA/QC data. This would include the raw data and calculations made to obtain the delivered results.

Prior to the laboratory data being used for interpretations it should be reviewed by the jurisdiction agencies with field data to identify any inconsistencies. If inconsistencies are identified appropriate action is to be taken that could require re-sampling, re-analysis, use data with caution, or no action may be required.

6.3. Data interpretation and reporting of findings

Internal review of the data and reports, consists of internal and external peer review, and is to be conducted according to the organisations publication and contractual requirements prior to submitting to the National Coordinator.

At the discretion of the National Coordinator the report may be submitted to a third party for external review. The authors of the report will then address all comments and edits requested by the National Coordinator and their reviewers prior to submitting the Final Report.

7. GOVERNANCE OF A NATIONAL SOIL CONDITION MONITORING PROGRAM

7.1. Governance structure and responsibilities

The program is designed to endure for several decades. To facilitate this a structure is proposed consisting of an Oversight Committee, National Coordinator and technical support group, Jurisdiction Teams, and a Central Soil Analytical Laboratory. The structure and responsibilities are summarised in Table 7-1 and described in more detail in the following sections.

7.1.1. Oversight Committee

The Oversight Committee consists of members that represent the client, The National Committee on Soil and Terrain and key users of the data. The main role is to provide high level direction and review for the Program, and includes the following tasks:

- provide direction to maintain relevance,
- obtain independent evaluation at least every 5 years,
- ensure that the Program maintains focus on required objectives and outputs,
- secure funds to maintain a long-term viability,
- advise on allocation of resources,
- review findings and identify relevance to national issues,
- determine direction and maintain relevance of business case,
- authorise changes that will improve or shift to meet requirements for National issues,
- advocate at a National level and when required at a Jurisdiction level the importance of the National Soil Condition Monitoring Program to maintain support, and
- determine the program termination.

7.1.2. National Team

The National Team includes a National Coordinator (with skills in management, liaison and monitoring), and a technical support group (with skills in database and data management, GIS, interpretation of analytical data, statistical analysis, soil archive operations, and contract management). The main role is to provide overall management of the project, specialist technical input, an enduring national focal point for data and information, and includes the following tasks:

- provide national management,
- report and liaise with the client,
- respond to, report and liaise with the Oversight Committee,

- advocate at a national level the importance and findings of the National Soil Condition Monitoring Program,
- maintain protocols and standards,
- maintain the proposed the schedule,
- conduct quality assessment and quality control,
- maintain the national datasets, undertake data management and quality of the data imputed,
- ensure the monitoring soil samples are placed in the national soil archive,
- co-ordinate with the central soil analytical laboratory to review results,
- provide high level skills in statistical analysis of the data to support the jurisdiction to manipulate and interpret their information,
- provide opportunities for training, transfer of knowledge, skills and lessons learnt between jurisdictions,
- organise and conduct meetings between the jurisdictions as required,
- co-ordinate reporting from the jurisdiction to ensure it is timely and in a standard format,
- prepare the national report,
- work with jurisdictions to maintain continuity of the Program, retention of staff with skills and knowledge, and training of new staff,
- financial and contract management at a national level of the Program,
- research and development, including analysis of data to guide the Program,

7.1.3. Jurisdiction Teams (for each State and Territory)

The Jurisdiction Teams are from agencies conducting the work in each jurisdiction, and includes Jurisdiction Representative (with skills in project management, communication, reporting and soil monitoring) and support team (with skills in field sampling, data preparation, data interpretation and reporting). Their main role is to manage and implement the Program, conduct field work, data interpretation, reporting and forward all data and soil samples to the national repository, and includes the following tasks:

- manage the program in their jurisdiction,
- liaise with the National Coordinator and technical support group,
- determine Monitoring Regions, Monitoring Units and Monitoring Site locations,
- identify and obtain permission from landowners for establishing sites,
- conduct the soil sampling,
- prepare and organise transport of samples to the Central Soil Analytical Laboratory or an approved alternative laboratory,
- co-ordinate with the laboratory to ensure that they have the correct sample information, soil samples, solve issues as they arise, and evaluate results,
- compile, review, and interpret the data collected,
- prepare monitoring reports,
- provide data to the national data repository in the required format,
- attend workshops and meetings as required,

- at a jurisdiction level seek synergies with other soil and environmental monitoring programs, source supplementary funding for additional work that is of importance to the jurisdiction that could be conducted at the same time or as an add on to the national work requirements,
- with the National Team identify Monitoring Regions, Monitoring Units and Monitoring Sites for expansion of the program as resources will allow,
- financial management at a jurisdiction level and reporting of expenditure to the National Program accounts,
- work with the National Team to retain staff and to train new staff,
- ongoing evaluation of the data, protocols and methods to refine and improve the Program,
- advocate at a jurisdiction level the findings and importance of the National Soil Condition Monitoring Program.

7.1.4. Central Soil Analytical Laboratory

The Central Soil Analytical Laboratory includes facilities and staff. The role is to conduct soil analyses and ensure standards are met.

Ideally all samples should be analysed at one laboratory facility to remove the possibility of inter laboratory differences. However it is possible that for reasons of capacity or a Jurisdiction Team has a working relationship with an alternative laboratory, that analyses are conducted at alternative laboratories. The role of the Central Soil Analytical Laboratory here will be to ensure standards and quality is met.

The role of the Central Soil Analytical Laboratory includes the following tasks:

- receive soil samples from jurisdiction teams,
- prepare samples for analysis,
- conduct soil analysis, including quality assurance and quality control checks,
- deliver results to Jurisdiction Representative,
- Quality Assurance with other soil monitoring laboratories.
- package and transport remaining sample to the soil archive operator.

Table 7-1. Summary of Governance Structure and Key Responsibilities.

Program Structure	**Key Responsibilities**
OVERSIGHT COMMITTEE (client, NCST, key users)	➢ Evaluation and direction ➢ Secure resources ➢ Advocate program ➢ Authorise major changes ➢ Determine termination ➢ Maintain relevance of business case
NATIONAL TEAM (National Coordinator, technical support group)	➢ National management and contracting ➢ Specialist technical input ➢ Advocate program ➢ Communicate findings ➢ Maintain standards ➢ Maintain quality ➢ Maintain national database and information ➢ Coordinate between the groups ➢ Financial management of Program ➢ Generate the national report
JURISDICTION TEAMS (Agencies from New South Wales, Northern Territory, Queensland, South Australia, Tasmania, Victoria, Western Australia)	➢ Manage project in jurisdiction ➢ Conduct soil sampling ➢ Compile, review, interpret data ➢ Prepare reports ➢ Provide all data, information and soils to the National database and archive ➢ Financial management ➢ Retain and train staff ➢ Advocate Program ➢ Communicate findings
CENTRAL SOIL ANALYTICAL LABORATORY	➢ Maintain standards ➢ Prepare samples ➢ Conduct analysis ➢ Deliver results ➢ Quality assurance for other laboratories

7.2. Endurance of the National Soil Condition Monitoring Program

The Program will need to operate for decades to obtain long-term trends in soil condition that it was designed to detect. To be consistent with this, the Program will be established in an enduring organisation with necessary funding for this as a permanent budget item.

The Program is designed to be as rigorous as possible to meet current needs, but is flexible to accommodate future monitoring requirements (such as other variables or more regular sampling events). The Program may expand to include additional Monitoring Units and/or additional soil variables to be included, if funding becomes available. It is also likely that the value of the Program would continue to grow as additional questions are asked of the sustainability of Australia's soil, agriculture and environment.

Subject to the availability of funds and the needs of the client being met, the Oversight Committee will determine the degree to which the Program endures. No criteria have been set by which the committee might determine when the National Soil Condition Monitoring Program should be terminated.

7.3. Privacy, Data Ownership, and Intellectual Property

Agreement between all participating agencies will be negotiated prior to the Program starting to address issues such as privacy, intellectual property and data ownership.

7.4. Issues for further consideration

This report outlines the results of extensive development and testing of field sampling strategies and protocols. Within the constraints of this project, a number of unresolved issues and concerns remain that require further consideration and decision before a national program can be rolled out.

Recommendations for the resolution of remaining concerns include:

- Further consideration of the location and number of priority monitoring units throughout Australia to ensure important strategic areas are not missed. 2 monitoring units per attribute, per jurisdiction should not be considered as adequate representation of soil land use combinations across Australia
- Spatial definition of target soil types is not adequate in many regions to properly plan a holistic sampling design. Any monitoring program should also be supported by adequate resourcing of regional soil inventory and mapping studies in addition to monitoring resources
- Additional sampling and data collection is required to answer the question of what is causing detectable changes in soil condition attributes. A national program should further consider the need to answer this question and be scaled up accordingly
- Soil property analyses, particularly bulk density and chemical analyses, need further development and documentation of explicit methods to ensure consistency and repeatability. Small changes in soil properties over time will be undetectable against sampling and analysis method limits.
- Inherent spatial and temporal variability of soil attributes requires considerable effort for statistically valid sampling. Significant resources are therefore required to implement a long-term, meaningful, national monitoring program. If resources are constrained then priority regions should be considered rather than attempting an inadequate broad national approach
- A national program would generate a considerable amount of data which needs to be properly managed and integrated between field, laboratory, reporting and storage phases. Long-term value of a monitoring program will be embedded in the future management and accessibility of the associated data asset. The Australian Soil Resource Information System with associated data standards and requirements should be fully supported to maintain soil condition monitoring data into the future.

8. RESOURCE REQUIREMENTS AND SCHEDULE

8.1. Schedule

The schedule proposed allows for the Monitoring Sites to be established as a staged approach over 5 years and revisiting of sites thereafter on the same rotation. While it would be useful to establish all sites in one season and then resample all sites 5 years later it is unlikely there would be sufficient manpower and organisational resources to operate in this way.

A staged approach offers a number of benefits: as data becomes available each year the program can be adapted and improved; provides continuity of work for people on the project; provides measurements for each year; smooths out the flow of funds required; maintains continuity and visibility of the project.

The first year would require substantial input to establish contracts and agreements, identity and train team members, implement data handling and storage requirements; identify sites and determine if they are suitable.

Years 1 to 5 will require substantial field work to establish Monitoring Sites, collect and organise baseline data, review and modify approaches as necessary, prepare initial data interpretations and findings.

The main focus for Years 5 to 20 will be to collect data, review, interpret and generate reports on findings.

8.2. Resource requirements

A summary of cost estimates for required staff and operational resourcing to implement and maintain a National Soil Condition Monitoring Program over 20 years are presented in Table 8-2.

	Years 1 to 5 Establishment of Monitoring Sites ($)	Years 6 to 20 On-going data collection of Monitoring Sites ($)
Oversight Committee	100,000	75,000
National Team	1,000,000	650,000
Jurisdiction teams (for 7 teams)	2,520,000	1,820,000
Central Soil Analytical Laboratory	1,550,976	775,509
SUB TOTAL for one year	$5,170,976	$3,320,509
TOTAL for all years	For 5 years - $25,854,880	For 15 years - $49,807,635

Table 8-1. Summary of the cost estimate to operate the National Soil Condition Monitoring Program (dollar figures are for 2011 and not adjusted for subsequent years).

These are significant resource requirements, but can be justified within the value of industry and agricultural productivity which is dependent on a healthy soil resource base.

The **gross value of Australian farm production** (at farm-gate) totals **$41.8 billion-a-year**. (*Farm Facts 2011*, National Farmers Federation).

The estimated $5 million per year **investment required for** this component of **soil condition monitoring** is **less than 0.01%** of the annual production value, which is **a small price to pay for sustainability** monitoring.

The 2001 Australian Agriculture Assessment (NLWRA 2001) estimated that over 50 million hectares of agricultural land are already experiencing impacts from soil acidity including reduced yields. An interest in enhancing soil organic carbon content exists because of the combined effects that this would have on soil productivity and the mitigation of greenhouse gas emissions (CSIRO 2009b).

Table 8-2 details the resources for establishing Monitoring Sites in Years 1 to 5.Table 8-3 shows the costs for on-going data collection and assessment of Monitoring Sites for Years 6 to 20 (an additional 15 years).Assumptions for calculating the cost estimate include: each jurisdiction establishes 2 Monitoring Units with 100 Monitoring Sites for each Monitoring Unit, 5 years to establish and 15 years of Monitoring (total of 20 years); each jurisdiction would have 1.5 full time equivalent staff for first 5 years and 1 full time equivalent staff thereafter; the National Team would have 1 full time equivalent coordinator, and 2.5 full time equivalents technical support staff to provide contractual, technical and data management support.

It is assumed that 40 Monitoring Sites would be established per year, 200 over 5 years. It is anticipated that 100 Monitoring Sites will be required per Monitoring Unit. As data becomes available and evaluated it may be that a less number is required, if there are sufficient sites available (not required for the initial 2 Monitoring Units) then additional Monitoring Units may be established to use these sites.

It is assumed that the samples collected during the establishment of the Monitoring Sites (Years 1 to 5) will be collected from 10 positions at 3 depths and analysed separately, they will not be bulked. For the on-going data collection (Years 6 to 20) the samples will be collected from 10 positions at 4 depths, and 75% of sampled layers from Monitoring Sites will be bulked and 25% will be analysed separately.

The Program may expand if funds are made available for additional Monitoring Units to be established and/or additional soil variables to be included. It is also likely that the value of the Program would continue to grow as additional questions are asked of the sustainability of Australia's soil, agriculture and environment. It would therefore be beneficial if the Program is established in an enduring organisation and that necessary funding is established as a permanent budget item.

Table 8-2. Resource requirements to establish Monitoring Sites for Years 1 to 5 (5 years).

Resource	Unit Number	Unit Cost ($)	Cost ($)	Sub total For 1 year ($)	Sub total For 5 years establish-ment ($)
National Team Calculation based for operations on a per year basis					
Staff				700,000	3,500,000
National Coordinator	100%	200,000	200,000		
Technical support group (field operations, database, GIS, Interpretation, statistical, archive, contract administration)	250%	200,000	500,000		
Operations				300,000	1,500,000
Consumables			50,000		
Transport, vehicle operations, travel and accommodation			50,000		
Computing hardware and software, data storage, access and web based distribution of information			100,000		
Archiving of soils			100,000		
Jurisdiction Teams Calculation based for operations on a per year basis				Cost scaled by 7, providing total for all jurisdictions	
Staff				290,000 by 7 = 2,030,000	10,150,000
Jurisdiction Representative	100%	200,000	200,000		
Field team (preparation, sampling, data preparation)	25%	180,000	45,000		
Reporting team (data analysis, interpretation, report preparation)	25%	180,000	45,000		
Operations				70,000 by 7 = 490,000	2,450,000
Field equipment		5000	10,000		
Consumables for field operations (sample containers, labels, shipping to laboratory)			25,000		
Transport, coring drill rig, vehicle operations, travel and accommodation			25,000		

Resource	Unit Number	Unit Cost ($)	Cost ($)	Sub total For 1 year ($)	Sub total For 5 years establish-ment ($)
Office consumables (field data cards, maps, landowner information sheets, computing hardware and software)			10,000		
Central Soil Analytical Laboratory Calculations based on 40 sites per year, 3 layers sampled, 30 samples per site (no bulking of samples), plus 10% reanalysis for quality checks					
Sample preparation				39,600 by 7 = 277,200	1,386,000
Drying, grinding, sieving, moisture content	1320	30	39,600		
Bulk density	1320	25	33,000	33,000 by 7 = 231,000	1,155,000
Soil Organic Carbon				78,408 by 7 = 548,856	2,744280
Total carbon analysis (Method 2.1)	1320	15	19,800		
Sample pre treatment to remove carbonate carbon (Method 2.2)	264	26	6,864		
Fractionation of soil organic carbon – direct measurement (Method 2.3)	264	26	6,864		
Fractionation of soil organic carbon – indirect measurement by mid infrared spectroscopy (Method 2.4)	1320	30	39,600		
Determination of mineralisable C and N (Method 2.5)	264	20	5280		
Soil PH				50,160 by 7 = 351,120	1,755,600
Soil pH in calcium chloride and water(Method 3.1)	1320	18	23,760		
pH buffering capacity by Mehlich Buffer Method (Method 3.2)	1320	15	19,800		
pH buffering capacity by titration (Method 3.3)	264	25	6,600		
Lime requirement for liming to critical pH (Method 3.4)	1320	0	0		
Estimating NAAR by ΔpH and pHBC (Method 3.5)	1320	0	0		

Resource	Unit Number	Unit Cost ($)	Cost ($)	Sub total For 1 year ($)	Sub total For 5 years establish-ment ($)
Estimating NAAR by carbon and nitrogen cycles (Method 3.6)	1320	0	0		
Operations				20,400 by 7 = 142,800	714,000
Soil archive containers (for storage of remaining sample)	1200	2	2,400		
Transport to soil archive	1200	5	6,000		
Data compilation and delivery, QA/QC,	1200	10	12,000		
Oversight Committee Calculation based for operations on a per year basis					
Operations				100,000	500,000
Annual meeting full group – travel, accommodation, facilities			30,000		
Ad hoc meetings smaller group – travel, accommodation, facilities			45,000		
Consumables, communications and operations			25,000		
Committee members time			0		
TOTAL				**$5,170,976**	**$25,854,880**

Table 8-3. Resource requirements for on-going data collection and assessment of Monitoring Sites for Years 6 to 20 (15 years).

Resource	**Unit Number**	**Unit Cost ($)**	**Cost ($)**	**Sub total** **For 1 year ($)**	**Sub total** **For years 6-20 ($)**
National Team Calculation based for operations on a per year basis					
Staff				500,000	7,500,000
National Coordinator	100%	200,000	200,000		
Technical support group (field operations, database, GIS, Interpretation, statistical, archive, contract administration)	150%	200,000	300,000		
Operations				150,000	2,250,000
Consumables			25,000		
Transport, vehicle operations, travel and accommodation			25,000		
Computing hardware and software, data storage, access and web based distribution of information			50,000		
Archiving of soils			50,000		
Jurisdiction Teams Calculation based for operations on a per year basis				Cost scaled by 7, providing total for all jurisdictions	
Staff				190,000 by 7 = 1,330,000	19,950,000
Jurisdiction Representative	50%	200,000	100,000		
Field team (preparation, sampling, data preparation)	25%	180,000	45,000		
Reporting team (data analysis, interpretation, report preparation)	25%	180,000	45,000		
Operations				70,000 by 7 = 490,000	7,350,,000
Field equipment		5000	10,000		
Consumables for field operations (sample containers, labels, shipping to laboratory)			25,000		
Transport, coring drill rig, vehicle operations, travel and accommodation			25,000		
Office consumables (field data			10,000		

Resource	Unit Number	Unit Cost ($)	Cost ($)	Sub total For 1 year ($)	Sub total For years 6-20 ($)
cards, maps, landowner information sheets, computing hardware and software)					
Central Soil Analytical Laboratory Calculations based on 40 sites per year, 4 layers sampled, 4 samples per site for 30 sites (bulking of samples) and 40 samples per site for 10 sites (no bulking of samples), plus 10% reanalysis for quality checks					
Sample preparation				17,600 by 7 = 123,200	1,848,000
Drying, grinding, sieving, moisture content	572	30	17,600		
Bulk density	572	25	14,300	14,300 by 7 = 100,100	1,501,500
Soil Organic Carbon				36,036 by 7 = 252,252	3,783,780
Total carbon analysis (Method 2.1)	572	15	8,580		
Sample pre treatment to remove carbonate carbon (Method 2.2)	143	26	3,718		
Fractionation of soil organic carbon – direct measurement (Method 2.3)	143	26	3,718		
Fractionation of soil organic carbon – indirect measurement by mid infrared spectroscopy (Method 2.4)	572	30	17,160		
Determination of mineralisable C and N (Method 2.5)	143	20	2,860		
Soil PH				22,451 by 7 = 157,157	2,357,355
Soil pH in calcium chloride (Method 3.1)	572	18	10,296		
pH buffering capacity by Mehlich Buffer Method (Method 3.2)	572	15	8,580		
pH buffering capacity by titration (Method 3.3)	143	25	3,575		
Lime requirement for liming to critical pH (Method 3.4)	572	0	0		

Resource	Unit Number	Unit Cost ($)	Cost ($)	Sub total For 1 year ($)	Sub total For years 6-20 ($)
Estimating NAAR by ∆pH and pHBC (Method 3.5)	572	0	0		
Estimating NAAR by carbon and nitrogen cycles (Method 3.6)	572	0	0		
Operations				20,400 by 7 = 142,800	2,142,000
Soil archive containers (for storage of remaining sample)	1200	2	2,400		
Transport to soil archive	1200	5	6,000		
Data compilation and delivery, QA/QC,	1200	10	12,000		
Oversight Committee Calculation based for operations on a per year basis					
Operations				75,000	1,125,000
Annual meeting full group – travel, accommodation, facilities			25,000		
Ad hoc meetings smaller group – travel, accommodation, facilities			25,000		
Consumables, communications and operations			25,000		
Committee members time			0		
TOTAL				**$3,320,509**	**$49,807,635**

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