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Design and operation of a UK soil monitoring network

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Steve Killeen

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Executive summary

Since 2003, the UK Soils Indicator Consortium (UKSIC) has been working to develop a set of suitable indicators of soil function that will allow us to monitor the current status and any change in soil quality. The next stage is to develop a UK soil monitoring network based on these indicators. A tiered monitoring network is proposed. Tier 1 assesses status and change at a broad scale, with monitoring at later tiers used to address specific issues at a finer scale. This project addresses the design of the Tier 1 monitoring scheme, which must be able to assess the current status of soils and identify changes over time.

This report presents four design options for a Tier 1 monitoring network. The different options are evaluated in terms of:

- Their ability to monitor the indicators with sufficient precision to provide meaningful results for a range of land uses with each country.
- The advantages and limitations of each of the design types.
- The potential cost of each option.

At the outset, a checklist was established to assist in the process of implementing a Tier 1 soil monitoring network across UK by setting out the type and level of information required to realise a design for actual deployment. Several knowledge gaps were subsequently addressed by the stakeholder workshop, but the checklist still remains incomplete. It is envisaged that the checklist should continue to be developed as the requirements for a UK soil monitoring network are refined.

A process map and set of standard operating procedures were developed in the later stages of the project to assist in the deployment of a monitoring scheme. These should progress alongside the checklist as an integrated implementation strategy, to be developed, updated and maintained to serve as a written historical record and in so doing ensure that future monitoring will have an invaluable reference source to return to.

As part of the checklist, a set of indicator specification tables were constructed to collate the necessary technical information for all 13 of the UKSIC indicators. This highlighted that there are around 30 different combinations of indicators and function, with a range of knowledge gaps. The most common of these are appropriate tolerance levels for the quality measures, and action levels reflecting different stakeholder requirements, particularly at the individual country-level since any scheme will primarily be reporting at this scale. Tolerance levels are a vital component since no design can be fully evaluated without this information. The project team used tolerance levels to test the design options, but these could not reflect all UKSIC indicator/soil function requirements. The outcomes from the results reported here must be considered within this context. Altering the tolerance levels could alter the performance of the individual design options and make some design options more feasible than currently demonstrated, although the relative performance of the options is unlikely to change. A key priority remains the completion of the indicator specifications, particularly the requirements for quality measures (with tolerances) and action levels. This information is essential for the development of the ultimate monitoring scheme.

Initial consultation with the project board identified four indicators that any final monitoring scheme must be able to successfully monitor and report. These canary indicators were soil organic carbon (SOC), pH, copper, zinc with priority reporting requirements at the land use level based on the National Land Use Database (NLUD) classification. At the stakeholder workshop, this was further refined to reporting for

seven land uses (heathland, bog, improved grassland, unimproved grassland, broad-leaved woodland, coniferous and cropland) and assessing status and change in SOC and pH within all countries. Some issues remained to be resolved regarding ultimate priorities for reporting (such as land use in country or country-level means), which will affect the allocation of sampling locations given that optimal allocation for one purpose will be sub-optimal for others. This in turn will influence the choices for stratification, sampling intensities and cost. It is however unlikely to change the relative performances of the sampling options.

This study compared two model-based schemes (grid and optimised grid) and two design based schemes (stratified random and clustered stratified random). The stratified random scheme was found to be the most suitable option for the specific questions being addressed, particularly in terms of the assessment of status and change in soil organic carbon. These findings from comparing model-based and design-based options for a UK soil monitoring network are in line with other published research. Although we have found that our model-based schemes were less suitable than a stratified random survey analysed by design-based methods for this particular project, there is no reason to criticise or avoid systematic surveys in general since they have the advantage of achieving good spatial coverage, with proportional representation of the regions of interest. Options to adapt grid sampling are discussed.

The improved performance of design-based options was most noticeable in the assessment of change in SOC, which has significant implications for soil monitoring to assess change in indicators. As temporal data become available, it should be a priority to establish whether this result holds for other indicators. This is the first time that observations from real data have confirmed results from simulation studies, which suggests that stratification could improve measurements of SOC change.

Although there are clear gaps in the availability of soils data to be able to design a comprehensive soil monitoring network, the UK is internationally recognised for its large-scale spatial and temporal soils information both at the UK and individual region levels. It has both stratified random and grid-based sampling schemes in place in most countries. These all have soils information dating back to the mid-1970s and a few have subsequently been re-sampled and have produced some of the first large-scale soils change data over an extended time period, while others are currently being re-sampled and will establish the first time series sampling of soils at this scale. This resource, and its scientific knowledge base, has established the UK at the forefront of national-scale soil monitoring with the information being used to inform development of soil monitoring schemes elsewhere. It would be difficult to justify establishing an entirely new scheme from new locations with no pre-existing data. The question still remains: how can we best use this information to our advantage? Based on the results from this project, a priority should be exploring the sampling options for gaining the required statistics from existing schemes, including the opportunities to bring together country-level schemes across UK to achieve “a whole greater than the sum of its parts”. Examples for future opportunities to achieve this goal are discussed.

In summary, the sponsors and end-users of a monitoring scheme must accept that, if they want the most efficient scheme to answer specific questions about particular reporting units, this will limit its future flexibility to some extent. On the other hand, if they want a sampling scheme that will be most flexible in the future, then it will not be ideal for answering specific questions that can be framed now. Decision-making should be based on full awareness of limitations for future expectations. Reviewing the outstanding technical issues raised in this project should be sufficient to establish the ultimate sampling framework for a UK soil monitoring network.

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1.1 Background

The soil resource has been the foundation of many nations and it will continue to be fundamentally important to us in the provision of many ecosystem goods and services. However, the soils resource, and importantly the functions it maintains, are under constant threat from many varied risks at a range of scales, from localised issues such as inappropriate management, local contamination, erosion and flooding to global issues such as atmospheric pollution and of course climate change. It is reasonable to assume that these, and as yet unknown risks to soils, will be maintained if not intensified in future decades. However, unlike air or water, the quality of soils across the UK has tended to be protected through indirect policies and legislation. This approach has undergone considerable review in recent years and there are now numerous European and national initiatives raising the profile of soil protection and use. A significant driver has clearly been the developing European Soil Framework Directive (European Commission, 2008). In parallel, the UK has taken a proactive approach to developing soil protection measures across all nation states through soil strategies, action plans and policy programmes. With this greater consideration of soil protection, there is the need to determine the state of UK soils and to develop processes to monitor future changes in soil quality.

1.1.1 UK Soil Monitoring Network

The UK Soil Indicators Consortium (UKSIC)[1] is a group of public stakeholders working towards development of a set of robust indicators of soil quality, and creating a scheme to monitor these indicators. Monitoring information is required to help policy makers understand the current state of the environment and how it is changing, and to understand the pressures placed upon it. Information from monitoring is needed to show how we are meeting national and international laws and agreements for protecting the environment. Additionally, monitoring information will also support the development and implementation of future soil and environmental policy and management guidance by providing evidence on the state of soils.

The information gathered from a UK soil monitoring network will be needed to address current policy issues, as well as having a degree of flexibility to be able to address as yet unknown policy issues. The design should therefore address not only the current highest priority policy indicators, but also other indicators/properties that would provide sufficient information to obtain a reliable understanding of the state of, and trends in, our soils. To meet these requirements, the approach being adopted by the UKSIC is to follow a tiered monitoring scheme that will be used to assess the status and change in a range of soil indicators that are related to the delivery of different soil functions. A three-tier monitoring scheme is envisaged by the UKSIC (Figure 1.1), with only Tier 1 monitoring being carried out at the national scale. This will be the focus of this project.

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[1] Information available online:
http://www.defra.gov.uk/environment/land/soil/research/indicators/consortium/index.htm

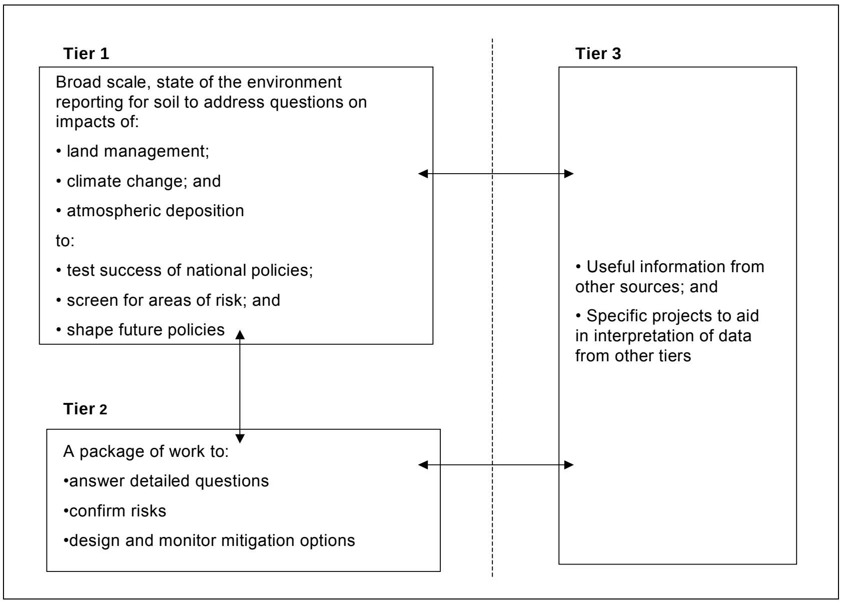

Figure 1.1 Three-tier monitoring network

Tier 1 must assess the current status and identification of trends in national soil quality. The key requirements to be addressed in the design of a Tier 1 assessment are therefore monitoring at a broad scale, and the delivery of information to report the state of soil at the level of each devolved administration - England, Northern Ireland, Scotland and Wales.

No soil monitoring scheme can be entirely comprehensive or so flexible that it can cope with all or any future changes in requirements, issues or resources. Thus, an important component of designing a UK soil monitoring network will be the identification, and clear documentation of assumptions, uncertainties and limitations relating to the different scheme options.

1.1.2 UK soil monitoring indicators

Monitoring will determine the status of a range of soil functions that are the basis for current developments in soil protection policy, including the EU Soil Framework Directive. These functions, as defined in the Soil Action Plan for England (Department for Environment, Food and Rural Affairs (Defra), 2004) are:

- Food and fibre production.
- Environmental interaction.
- Foundation for the built environment.
- Support of ecological habitat and biodiversity.
- Protection of cultural heritage.
- Providing raw materials.

The UKSIC has funded a series of projects to identify robust indicators of soil quality with which to assess these soil functions. A sub-set of soil quality indicators was subsequently selected by UKSIC to form the basis of the design of a Tier 1 soil monitoring scheme for the UK (Table 1.1). However, it has to borne in mind that there are not, as yet, indicators for all functions, nor are the current selection of indicators comprehensive for each function. Furthermore, the required information on the spatial and temporal variability of all of these indicators to inform a fully comprehensive design of a UK soil monitoring network is lacking (Emmett *et al.,* 2007a).

Table 1.1 Indicators selected to inform on each soil function

Soil function	Selected indicators	Reference	Action levels
Food and fibre production	Soil pH, Soil organic carbon, Bulk density, Olsen P, Total N, Aqua regia extractable metals (Cu, Cd, Zn, Ni); Extractable Mg & K,	Defra, 2005a	Environment Agency 2006b
Environmental interaction	pH, Soil organic carbon, Bulk density, Olsen P, Total N, Aqua regia extractable metals (Cu, Zn, Ni)	Environment Agency, 2006a	Environment Agency, 2006a
Foundation for the built environment	No indicators recommended	Defra, 2005b	-
Support for ecological habitat and biodiversity	pH, Olsen P, Potentially mineralizable N Soil Organic Carbon, C/N ratio, Extractable K	Environment Agency 2006b	Environment Agency 2006b
Cultural heritage	pH, Soil Organic Carbon	Davidson & Wilson 2006	-

At the outset of this design project, the primary policy requirement was to report on soil organic carbon trends (SOC) for a Sustainable Farming and Food Strategy (SFFS) headline indicator (Defra, 2006). However, the information gathered from a UK soil monitoring scheme will also be needed to address other on-going policy issues as well as having a degree of flexibility to be able to address as yet unknown policy issues. With developments of the EU Soil Framework Directive, member states will be required to identify areas at risk from a range of threats to soils, through the use of existing monitoring schemes, for example. A UK soil monitoring network should therefore support the screening for geographical areas of soils at risk. The SNIFFER project LQ09 (Emmett *et al*., 2007a) identified where indicators selected by UKSIC could be used to inform on specific risks, although there are other approaches to determining risk areas. Table 1.2 summarises the links between the UKSIC selected indicators and soil threats.

Table 1.2 Relevance of the selected soil quality indicators to soil threats identified in the EU Soil Framework Directive.

UK-SIC Indicators	EU threats to soil								
	Decline in SOM[2]	Soil contamination	Soil erosion	Soil compaction	Landslides	Soil salinisation	Decline in soil biodiversity	Sealing	Desertification
Topsoil soil organic matter content/SOC	■								■
Soil pH		■				■			
Total Cu		■							
Total Zn		■							
Bulk density	■			■					
C/N ratio	■								
Olsen P									
Total N									
Total Cd		■							
Potentially mineralisable N		■							
Total Ni		■							
Extractable K									
Extractable Mg									

Notes: Adapted from SNIFFER LQ09 (Emmett, *et al*., 2007a); Bulk density included not as an indicator of carbon itself but as an essential measurement to derive carbon stock.

1.2 Objectives

An ultimate objective of the UKSIC is to develop a UK soil monitoring network, and framework for delivery, that is based on the indicators of soil function identified by previous UKSIC projects. The information collected by this scheme should assess the current status of soils and changes over time at a UK and devolved administration level. The information will be used in various ways by a range of UK stakeholders, and will inform on current policies relating to soil and the development of future evidence-based policy and guidance to help ensure the sustainability of the soil resource in the UK.

This project was initiated to address the following objectives:

- To develop a range of options for a UK soil monitoring network.
- To provide a detailed breakdown of costs for the components of the monitoring framework and to identify constraints, uncertainties and assumptions.
- To build upon previously funded research on the design of monitoring schemes, soil sampling and analysis and interpretation.
- To present these options to UKSIC and agree on a scheme to be further developed.
- To develop a framework for the delivery of the monitoring scheme to include guidance on soil sampling, analytical methods to be used, interpretation of data and soil and data storage.

The project delivery was phased with partner organisations taking responsibility for individual tasks (Appendix A). This report details the main activities and outputs towards meeting these objectives. The main activities included:

- Developing a checklist for a UK soil monitoring network (Chapter 2).
- Applying the latest, and most robust, statistical techniques in the development of options for a UK soil monitoring network (Chapter 3).
- Critical assessment of the performance of the different schemes using approaches developed and applied in previous UKSIC and other projects (Chapter 4).
- Selection of the preferred scheme in consultation with UKSIC (Chapters 4 and 6).
- Design of a framework for delivery of the monitoring scheme, including the development of appropriate Standard Operating Procedures (SOPs) for each step (Chapter 5).

A UKSIC consultation workshop was held as part of the selection of the preferred scheme. The primary objective was to reach a consensus on a common approach to Tier 1 soil monitoring across the UK to support the final selection of a soil monitoring network. Decisions reached by the stakeholders at the workshop had significant implications for assessing the different network options. Rather than revise the original report, the outcomes of the workshop have been included in text boxes within the relevant sections of this report. The influence of these outcomes on the results and conclusions of the original report are also included as text boxes at the end of each section as appropriate, and reflected within the conclusion.

2 Checklist for a UK soil monitoring network

2.1 Introduction

At the outset, a checklist was established to assist in the process of implementing a Tier 1 soil monitoring network by setting out the type and level of information required to realise a design. A checklist is intended for use by those with responsibility for commissioning, designing and implementing a soil monitoring network. The development and updating of a monitoring checklist is a useful way to establish the specific requirements of a monitoring network, detail the information to be collected and other requirements for the design and operation of a soil monitoring network. A primary aim for this project was that the checklist would capture essential details, particularly the objectives, quality measures and constraints, to support the subsequent tasks of designing and assessing the performance of the options for a UK soil monitoring network.

The structure of the checklist for a UK soil monitoring network builds upon the experiences in implementing large-scale soil monitoring schemes of the project consortium partners and others, specifically MacKenzie *et al.* (2002) and De Gruijter *et al.* (2006). The information to populate the checklist was obtained through a process of consultation with the project team and stakeholders from UKSIC. Gaps in a checklist can continually be revised as the information base develops. As previously noted, the outcomes from a workshop held with UKSIC stakeholders in the later stages of the project led to further clarifications and alterations to the requirements of a UK soil monitoring network with consequences for a preferred design option. These consequences are highlighted as text boxes in the relevant sections of the report.

Certain information is not yet available to complete key sections but it is envisaged that these would be completed once a network design has been finalised and prior to the actual operation of the scheme. Information from the checklist, including revisions from the workshop outcomes, was used as the basis for the design and implementation phases of this project.

There are two main elements to the checklist. Firstly, there is the element that refers to the development of the monitoring network in its entirety, and secondly there are individual specifications for each indicator. The checklist for the scheme is described in the following subsections and is laid out to detail the following: purpose, monitoring interval, indicators, canary indicators, action levels, quality measures, reporting classes, interpretation, sampling, sample analysis, supplementary information, archiving and the reporting of results. A series of specification tables has been developed for each indicator to aid the design and assessment of the performance of individual design options (Appendix B).

2.2 Purpose of a UK soil monitoring network

The overriding purpose of a UK soil monitoring network has been established by the UKSIC with a focus on delivering soil information directly relevant to policy issues. It is an important point that the rationale for a UK soil monitoring network has been drawn up by UK government departments and agencies to meet their policy obligations and objectives. This constrains the design of a network but also imposes limitations on the current and future flexibility of monitoring soil quality.

The specific purpose of the monitoring network is:

- To establish the current state of our national soils, and identify trends in national soil quality at a Tier 1-level, by the deployment of a set of policy-relevant and scientifically robust indicators of soil quality that have been selected to cover all of the functions of soil and meet the varied requirements of the UKSIC member organisations. Figure 1.1 illustrates the primary requirements of Tier 1 monitoring and the relationships between the three tiers.
- To enable the collection of soil quality information reportable at a UK and devolved administration level to provide evidence for informing soil policy development. The current requirement is for reporting information at the level of devolved administrations (England, Northern Ireland, Scotland, Wales), and not for the UK as a whole. Reporting at English Government Office Regions was also considered useful, but dependent upon cost.
- To have the capacity to be tailored to available resources and individual organisation needs. At present, the primary policy requirement is to report on soil organic carbon trends (SOC) for a Sustainable Farming and Food Strategy (SFFS) headline indicator. However, the information gathered from a UK soil monitoring network will also be needed to address other on-going policy issues as well as having a degree of flexibility to be able to address as yet unknown policy issues.

Workshop Box 1: Scope of a UK soil monitoring network

A UK soil monitoring network may not report at the UK level since reporting requirements are primarily devolved to the individual country level. However, it is appreciated that there would be scientific merit in having cross-UK compatibility of soils data. For example, monitoring organic soils in England could benefit from comparisons with data from Scotland where organic soils are more prevalent. The scope has consequences for the development of the monitoring network. The optimal design option for one country may not reflect the optimal option for the majority of countries or for the UK as a whole. The ultimate choice may reflect a balance between the benefits of having a compatible scheme across the UK and technical or economic implications at the country-level where the compatible scheme may be sub-optimal. It was acknowledged that there is substantial relevant research activity in soil monitoring and indicators within the UK at present (such as NSI for Scotland, Countryside Survey and the Environment Agency (Environment Agency, 2008a and b)). Consideration was given to making decisions using the best data currently available or waiting for information shortly forthcoming. It was decided to progress with available information with the view that UKSIC could review what decisions need to be made and assess the need to wait for forthcoming information.

2.3 Monitoring interval

It is implicit that a monitoring network will involve a series of repeated samplings over known intervals. The repeat interval has not been established for the UK soil monitoring network, but a five-year interval has been proposed for soil organic carbon to address specific policy issues. This interval was adopted for the design phase although different intervals maybe required for other purposes at a later stage.

2.4 Indicators for monitoring

The series of indicators of soil quality, selected by the UKSIC, form the basis of the design of the Tier 1 monitoring scheme. The selection process is detailed in a series of reports from the UKSIC. The most relevant report to the designing of a UK soil monitoring network is that from the Environment Agency's Bath meeting (Environment Agency, 2006a) and the subsequent short note (Environment Agency, 2006b), which together provide specific detail on the statistics, quality measures and so on for each of the selected indicators. Table 2.1 presents the list of indicators selected by the UKSIC for the assessment of soil functions in a national soil monitoring network.

Table 2.1 Indicators of soil quality prioritised by UKSIC for a UK soil monitoring network.

Soil function	Selected indicators		Reference	Action levels
Food and fibre production	pH Bulk density Total N Aqua regia extractable metals (Cu, Cd, Zn, Ni)	Soil Organic Carbon Olsen P Ext. Mg & K	Defra 2005a	Environment Agency 2006b
Environmental interaction	pH Bulk density Aqua regia extractable metals (Cu, Zn, Ni)	Soil Organic Carbon Olsen P Total N	Environment Agency 2006a	Environment Agency 2006a
Support for ecological habitat and biodiversity	pH Olsen P Potentially min. N	Soil Organic Carbon C/N ratio Extractable K	Environment Agency 2006a	Environment Agency 2006b
Cultural heritage	pH	Soil Organic Carbon	Davidson and Wilson, 2006	Environment Agency 2006b

Note: At present there are no indicators for the soil function of providing raw materials or foundation for the built environment.

A substantial level of information is required on each of these indicators to ensure that monitoring will address the specific requirements of stakeholders, as well as supporting the design of options. To capture this information, a series of specification tables have been developed to summarise the information for each indicator by soil function in a consistent manner. It is envisaged that these tables will be updated as the development of indicators for each function evolves. The specification tables for the indicators listed in Table 2.1 are provided in Appendix B. Table 2.2 provides an example specification table using the Defra SFFS indicator of soil organic matter content[2] , to illustrate the level information ultimately required.

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[2] The Defra SFFS Headline Indicator of soil organic matter content is determined from soil organic carbon, that is, the UKSIC indicator of interest. Soil organic matter can be derived from estimates of SOC and vice versa, depending upon the analytical methods used.

Table 2.2 Checklist information on the Defra Sustainable Food and Farming Strategy headline indicator of soil organic matter.

Function	**Food & fibre production**		
Indicator required	**Soil organic matter (Defra SFFS headline indicator)**		
Policy objective	To halt the decline of soil organic matter caused by agricultural practices in vulnerable soils by 2025.		
Source	Defra, 2006		
Indicator assessment	To determine whether there have been significant losses in soil organic matter (SOM) caused by agricultural practices in vulnerable soils .		
Assessment interval	E = start year 2008/09, report on SOM 2010/11 (approx.) and again before 2025. All other administrations = 5 years.		
Domains of interest	Devolved administrations and land uses.		
Indicator variable (unit)	Measured values of topsoil soil organic carbon content (g kg^{-1}), reported as organic matter..		
Measured variable (unit)	Measured values of topsoil soil carbon content (SOC %) converted using a pedotransfer function (previously SOC x 1.724).		
Indicator parameter	- Mean, standard deviation and upper and lower 95 confidence limits for specified land uses, following transformation to normal distribution. - Estimated change at 95% confidence since last sampling (or earlier samplings).		
Indicator quantity	Status and change in the mean soil organic matter content for agricultural land uses.		
Type of result	Quantitative: Is soil organic matter content significantly different to previous estimates? Qualitative: Is soil organic matter content progressing towards the targets set for each land use?		
Quality measure (d: tolerance level)	(i) The width of a 95% confidence interval for the true mean SOM (g/kg) is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean SOM 9g/kg) is 2d or less		
Land use (other than Land Cover classes)	Arable/rotational grass	Permanent managed grass	Managed semi-natural grassland
Action level (mean)	Progression to 50 g kg^{-1} for E&W	Progression to 75 g kg^{-1} for E&W	Progression to 220 g kg^{-1} for E&W
Soil depth	0-15 cm topsoil		
Sampling procedure	Direct comparison with NSI E&W requires sampling using Soil Survey for England and Wales sub-sampling by auger.		
Analytical method	SOC by method comparable to LOI + Walkely Black, but preferably dry combustion method.		
Archiving	Air-dried 2 mm sieved soil sample .		
Additional information	Change relative to previous values (NSI E&W); probably moving to stock estimates with measurement of bulk density. The Defra SFFS Headline Indicator of soil organic matter content is determined from soil organic carbon, that is, the UKSIC indicator of interest. Soil organic matter can be derived from estimates of SOC and vice versa, depending upon the analytical methods used.		

Notes: *d* = tolerance interval, which needs to be defined (Section 2.7).

Workshop Box 2: Detailed specification of indicators in the checklist
It became apparent during the project that the specifications for individual indicators required further work. Not all the necessary information was available to allow individual indicators to be considered in the design of a monitoring network or to ensure that resultant data from monitoring would be what was required within the stated policy context.

Requirements of policy-orientated soil indicators

- **S**pecific: *responsive to human-induced changes to the environment*
- **M**easurable: *robust methods with defined precision (tolerance); simple and cost-effective to measure*
- **A**chievable: *signal distinguishable from noise; applicable to monitoring*
- **R**esult-oriented: *provides diagnostic or predictive information with consequential policy actions (action levels with tolerance)*
- **T**ime-based: *provide reliable information over a pre-determined timescale*

It was agreed that there was a requirement for follow-up activities by UKSIC stakeholders beyond the timescales of this project. Key actions were:

- As a priority, the checklist information for status and change in SOC and soil pH would be completed by UKSIC, with the identification of acceptable tolerances for Tier 1 monitoring of each aspect of these indicators for all relevant functions. This should also include clarification of which aspects of theses indicators may be more suited to Tier 2 monitoring.
- UKSIC to consider the unresolved issues for the remaining indicators in turn. The specification tables can be used to assist this as they systematically identify where information is insufficient or not currently available.

2.5 Identification of canary indicators

Canary indicators are those identified as critical to current monitoring objectives. An option for a monitoring network must therefore be suitable for these priority indicators (that is, able to determine status and detect change with adequate precision) if the design option is to be considered for Tier 1 monitoring. Evidence that one or more canary indicators cannot be adequately monitored by a design would be grounds to reject a network design. Other indicators may be feasible, but the canary indicators will be the touchstone in any decision-making process. In consultation with the project board, the list of indicators was assessed according to policy requirements. Soil organic carbon and soil pH were definite canaries. Total copper and total zinc were high priorities, though with specific land use interests. There was no consensus on the remaining indicators as canaries.

Workshop Box 3: Extrapolating from results for canary indicators to other indicators
The question was raised at the workshop as to whether the results from the canary indicators would reflect likely results for indicators where there is currently insufficient information to include them in the design phase. In essence it is not possible to extrapolate results for canary indicators to other indicators since each indicator has, or will have, its own distribution, quality measures (such as action levels and tolerances) and constraints. The project considered it to be more important to establish the priority indicators (the canaries) for a UK soil monitoring network to enable the design phase to move forward. Where information is lacking on other indicators, additional soil parameters could be measured concurrently in a monitoring programme. This would support future consideration of the suitability of a design to monitor these indicators and achieve a robust baseline.

Workshop Box 4: Common indicators for all countries within a UK soil monitoring network
In the first phase of the project, the 13 UKSIC selected indicators were narrowed down to SOC, soil pH, total copper and total zinc as priorities (“canaries”), although there remained the wish to include as many indicators as possible within the network. This selection was reviewed at the workshop, prior to reviewing the design options for a UK soil monitoring network.

Status and change of both SOC and soil pH were considered essential by all groups, with the caveat that there would need to be consideration of any compromises arising, for example, if the priority is monitoring change then what would be the consequences on monitoring status in each country? There was no common agreement on the inclusion of other indicators as canaries across all groups or by countries.

The workshop outcome was an agreement to move forward with status and change in SOC and pH as primary indicators for monitoring across all countries. These priorities have therefore been considered in the final recommendations.

2.6 Action levels

For Tier 1 monitoring, UKSIC proposes to use previously established values for each indicator to determine the relevance of status or change in an indicator with respect to the individual soil functions. Deviations from these values would indicate that some action is required on a specific soil function, with possible elevation to Tier 2 monitoring. These values are known by different names for different purposes (such as trigger values, thresholds or change points). For consistency within this report, we have designated these values as “action-levels” (c.f. de Gruijter *et al*., 2006). Table 2.3 summarises the information available on current action-levels for each indicator by soil function. Further details where available are presented within the specification tables for each indicator (see Appendix B).

Table 2.3 Information available on current action-levels within individual soil functions for the UKSIC indicators of soil quality.

Indicator	Food and fibre production	Environmental interactions	Support for ecological habitat and biodiversity	Cultural heritage
Soil organic carbon (% or g kg^{-1})	Two sets (i) Defra SFFS: specified targets for land uses (ii) specified values for rainfall classes within agricultural land uses	Broad ranges for land uses	Change of -/+ 20% from previous sampling	Change of -/+ 20% from previous sampling
Soil pH	Specified values for specific soil types within land uses	Specified values for specific soil types	Two sets (i) specified values for land uses, (ii) Δ -/+ 0.5 pH units from previous sampling	Change of -/+ 0.5 pH units from previous sampling
Total Cu (mg kg^{-1})	Specific values for soil pH classes in agricultural land	Risk characterisation ratio >=1	n/a	n/a
Total Zn (mg kg^{-1})	Specific values for soil pH classes in agricultural land	Risk characterisation ratio >=1	n/a	n/a
Bulk density	Two sets of specified values for agricultural land	Specified values for soil types within land uses	n/a	n/a
C/N ratio	n/a	Min-max values for land uses	n/a	n/a
Olsen P	Index values for agricultural land uses	>60 mg l^{-1}	Δ -/+ 5 mg l^{-1}	n/a
Total N	Ranges for soil types		n/a	n/a
Total Cd (mg kg^{-1})	3 mg kg^{-1}	n/a	n/a	n/a
Potentially mineralisable N	n/a	n/a		n/a
Total Ni (mg kg^{-1})	Specific values for stated land uses	Risk characterisation ratio >= 1	n/a	n/a
Extractable K (mg l^{-1})	Specific values for stated land uses	n/a	Δ -/+ 50 mg l^{-1}	n/a
Extractable Mg (mg l^{-1})	Specific values for stated land uses	n/a	n/a	n/a

Notes: Further details in Appendix B

Workshop Box 5: Action levels
To design the optimum scheme UKSIC and other stakeholders need to refine the exact detail of information required from monitoring for each indicator. One approach would be to review the likely actions if results from monitoring were to deviate from expected or required levels (the action levels) and the certainty required from this information before action would be taken (tolerance levels).

In being used as a soil quality indicator, a soil parameter will be used to assess a specific function against specified criteria that will include action levels relevant to individual end-user requirements and based on the best current scientific knowledge. For example, soil phosphorus action levels may be different in Scotland compared to England due to the predominance of organic soils. Action levels will be required for both status and change in an indicator. It may be that a specific aim of future monitoring will be to obtain sufficient information to help establish suitable action levels for future indicators.

In setting these levels, it should be clear what the consequences will be if these levels are infringed. At present, the Defra SFFS SOC indicator is the only indicator where detailed action levels exist for specific land uses. The review of the indicator specifications (see Box 2) addresses the information gaps.

2.7 Quality measures

Defining the quality measures for each indicator is essential for optimising the design of a monitoring network as well as post-sampling evaluation of the information gained from monitoring. It is, in essence, the translation of the purpose into specific requirements for each indicator. It defines how the information obtained from monitoring is to be used for reporting and to compare against action levels.

Three quality measures are detailed by de Gruijter *et al*. (2006): utility, geometric and statistical. Statistical quality measures best reflect the current requirements from a UK soil monitoring network. Statistical measures reflect the accuracy, precision or reliability of the data. Common measures are the standard error, confidence intervals, error variance and so on. These are commonly termed “tolerance levels”. Statistical measures are easier to apply than utility measures, but generally less closely related to the actual use of the data. These measures require stochastic models of variation for each indicator as prior information either in the form of prior estimates of one or more variance components, or in the form of geostatistical or time-series models. All the current UKSIC indicators relate to statistical measures of quality, however there are issues over the availability of sufficient information on variation. To be consistent with other regimes, UKSIC stated requirements for the following quality measures from the information generated in monitoring indicators of soil quality across the UK.

- **Description of an indicator’s mean, standard deviation and upper and lower 95 confidence limits for the relevant reporting classes following transformation to normal distribution**. For example, for SOC, the mean value of carbon for a particular land use within England is estimated as 20 mg kg^{-1} with 95 per cent confidence that the true value of the mean lies between 18 and 22 mg kg^{-1}. The tolerance interval in this instance has been set at ±2 mg kg^{-1} (*for illustration only*)
- **Determine the significance of any change in an indicator for the relevant reporting classes from previous samplings**. For example, for SOC, the estimated change for a particular land use over 10 years is 2mg kg^{-1} with a 95 per cent confidence that the change is significantly different to

zero. In this instance, the tolerance interval has been given as 2 mg kg^{-1} (*for illustration only*).

- **Determine whether an indicator deviates significantly from an action-level**. For example, for the risk characterisation ratio of copper, the estimated RCR of permanent grassland in Wales is 1.2 (example only) with 95 per cent confidence that this value obtained from monitoring is significantly different to 1 (which is the action-level). In this instance, the tolerance interval would be defined for the indicator value at the 95 per cent confidence level.
- **Determine what proportion of samples deviate from an action-level for a particular indicator**.

The requirements for quality measures differ with each indicator and function (see Appendix B). However, for the first two points above, either the spatial and/or temporal information is often not available to finalise the definition of the quality measures. These have been left to be updated when sufficient data become available.

A key aspect of the quality measures, as highlighted above, is establishing the tolerance intervals acceptable to UKSIC for its purposes; that is, what level of uncertainty are they prepared to accept in the monitoring information. These tolerance levels will differ for each indicator for each function – and potentially for each action level within each function – dependant upon individual UKSIC policy requirements. For example, if UKSIC wants to know whether the mean estimated soil pH for land use class A is lower than the action levels for that class, this can be addressed as follows:

- If the action level for a given land use class was pH 4.5, and the estimated mean pH was 4.2 (from monitoring results), we could then compute the probability that the true mean pH fell below the threshold (making some assumptions about distributions that are generally reasonable for sample means). This would be a post-hoc evaluation of uncertainty (that is, it is for a particular case when we know what the estimate and its variance are).
- In advance, given estimates of the variance of the sample mean, we could say that an estimate of the mean pH for a given land use class will have a 95 per cent confidence interval of +/- d. This means that, with 95 per cent confidence, we could detect a case where the true mean falls beneath the action threshold by *d* units or more, but if the true class mean falls beneath the action threshold by less than *d*, then we have a lower level of confidence of detecting that fact.

It is the latter criterion that offers a quality measure for a sampling scheme. An acceptable tolerance value of *d* must be set by the end-user based on their requirements. Note that *d* must also be realistic, for example a quality measure set as "detect change with 95 per cent confidence" implies that *d* is zero which cannot be achieved if there is any variability of observations within the class (which of course there always is). This information can then be used to define the sampling intensity required to meet the required tolerance levels.

Tolerance levels have not been established for most of the UKSIC listed indicators. Therefore, to proceed in designing options for a UK soil monitoring network, the project set sensible tolerance values using available information on the canary indicators. These offer the opportunity to establish the relative performance of the different design options but do not in any way reflect what UKSIC may consider appropriate as tolerance levels for its purposes.

Workshop Box 6: Tolerance levels acceptable for UKSIC policy purposes

Tolerance levels are essential to complete an assessment of different schemes. Sample numbers, design performance and resourcing all relate to tolerances with potential to optimise sample allocation if tolerances are known in advance. Tolerance levels need to be established for each indicator for each land use, policy issue and each country. Basic principles are:

- Levels will differ depending on individual UKSIC policy requirements.
- Acceptable tolerance value of *d* must be set by the end-user; that is, what level of uncertainty is acceptable in the monitoring information.
- This information can then be used to define the sampling intensity required to meet the required tolerance levels within individual design options; it will not alter the relative performance of different design options.
- A common UK approach to indicators would benefit from an agreed set of tolerances for this purpose, but these may need to be set at the country level, depending on individual reporting requirements or specific circumstances.

For this project, pre-established tolerance levels were only available for SOC change and pH change; SOC change tolerance of +/- 20 per cent of baseline SOC and pH change +/- 0.5 units. However, assessment of the design options indicates that these tolerance levels may be rather restrictive for UKSIC purposes. In addition, power analyses highlighted that tolerance levels based on percentages and absolute values have different consequences for sampling requirements. Ultimately acceptable tolerance levels will be needed for all UKSIC indicators but this requires additional effort beyond the scope of this design project.

Outcomes from the workshop were that (i) the Project Board/UKSIC will establish tolerances that are acceptable for their purposes, the priority being by land use for SOC status (in particular for SFFS), SOC change, pH status and pH change, and (ii) UKSIC needs to review the indicator tables and identify whether tolerance levels are required for all indicators for every purpose.

2.8 Reporting classes

If feasible, all indicators will be monitored across the whole of the UK with sufficient detail to allow assessments of status and change in each indicator for each devolved administration (England, Northern Ireland, Scotland and Wales). There is no current policy requirement to report indicators at a UK level. For each administration, there are additional requirements to assess indicator status and change in land use related reporting classes. NLUD (2003) reporting classes were agreed as the basis for reporting land use, in the first instance. Table 2.4 provides further information on NLUD Land Cover classes. In addition, individual indicators have specific reporting classes for different action levels. These additional levels of reporting can add considerable limitations into designing a monitoring network, although they could be accommodated by adapting land use classes and through information gained in the field.

Table 2.4 National Land Use Database Land Cover Classification

Order		Group	
C10	CROPPED LAND	C011	field crops
		C012	fallow land
		C013	horticulture
		C014	orchards
C20	GRASS	C021	improved grass
		C022	unimproved grass
		C023	recreation and amenity grass
C30	WOODLAND AND SHRUBS	C031	conifer woodland
		C032	mixed woodland
		C033	broad-leaved woodland
		C034	shrub
C40	HEATHLAND AND BOG	C041	heathland
		C042	bracken
		C043	bog
		C044	montane
C50	INLAND ROCK	C051	inland rock
C60	WATER AND WETLAND	C061	standing water
		C062	running water
		C063	freshwater marsh
C70	COASTAL FEATURES	C071	seas and coastal waters
		C072	inter-tidal sand and mud
		C073	salt marsh
		C074	dunes
		C075	coastal rocks and cliffs
C80	BUILDINGS AND STRUCTURES	C081	building
		C082	other built structure
C90	PERMANENT MADE SURFACES	C091	metalled roadway
		C092	railway
		C093	pathway
		C094	other made surface
C100	GENERAL LAND SURFACES	C101	multiple surface
		C102	bare surface

The information provided by the project board indicates a desire to report on a diverse range of reporting classes, other than land cover class within country. Further decisions are required to help establish the extent to which flexibility should be built into the design. Three distinct types of additional reporting class can be identified:

- **Additional reporting classes whose location can be spatially identified beforehand.** Examples of this are some of the agricultural classes, which should be identifiable with a high degree of accuracy using IACS datasets within a GIS setting or soil textural class available from soil maps. With a considerable amount of effort these classes could be built into the design of a monitoring scheme and hence allowed for in drawing the locations to be visited. If obtaining information about these additional reporting classes is required, we recommend that they be included in the sampling stratification after the necessary additional GIS work. An alternative approach is to use aerial photographs to screen randomly selected points within the design strata; however, this would have the disadvantage of still needing to estimate the amount of each such reporting class in each design class, and the number of trial-and-error points to be drawn before reaching all targets may be large.

- **Reporting classes that can only be identified in the field**. Classes based on the clay content of soils required for reporting carbon fall into this category. Good sample sizes for such classes can not be guaranteed *a priori*. These could be accommodated in the design through knowledge of their relative frequencies in each design stratum and by drawing additional sampling locations to make reasonable coverage of these classes likely. A more exact method of dealing with this issue would be some form of quota sampling, in which locations are drawn at random within strata, visited, and then a probabilistic rejection rule applied to determine whether or not to include the location in the sample. In either case, obtaining reasonable sample sizes from rare classes would require a considerable amount of effort over and above that required for getting adequate sample sizes for the classes known *a priori*. In addition, the task of combining estimates across design strata to form a mean for the reporting class will contain additional variability due to errors in estimating the extent of the reporting class within each design class.
- **The distinction between the spatial land use classification that is used to design a sampling scheme and the land use allocated to visited locations by a field surveyor.** For example, grassland pockets will be found in land use classes such as woodland and heathland, and so may be selected for sampling from the woodland or heathland land use classes. The question is: to which reporting class should such samples be allocated? There is a strong argument for allocating the site to the expected (rather than observed) land use, as we then know the spatial domain to which the sample refers. However, this would mean that data from different land uses would be reported in a single reporting class. This would not preclude some secondary analyses for misclassifications that occur frequently.

Workshop Box 7: Common reporting units
The objective was to reach a final consensus on reporting units across UK since this information would be required to establish the ultimate sampling design (that is, for stratification) and in the reporting of indicators from the information gained through monitoring.

A reduction in land use reporting units from the NLUD Group level would help in obtaining sufficient sampling coverage of all land uses in all countries and in optimising a design option. Breakout sessions and round-table discussion reached a consensus on a mix of the NLUD orders and classes that would be used for reporting across all countries; heathland, bog, improved grassland, unimproved grassland, broad-leaved woodland, coniferous and cropland.
Issues discussed:

- It was discussed that the best strategy would be to maintain NLUD orders by sampling all classes within these orders, but reporting could reflect class-level estimates, heathland and bog would be reported separately for example.
- The consensus was that woodland should not be grouped. Although coniferous woodland is likely to decline in future it is currently important and different from broad-leaved so should be included as a separate land use.
- There are no indicators with consequent actions in the urban environment and sampling urban soils would require different strategies than country-wide monitoring. It was agreed that urban areas were sufficiently different to warrant a separate monitoring scheme.
- There remains the issue that ley grassland is allocated to improved grassland within the NLUD and it would be difficult to identify ley within this class. However the SFFS SOC indicator places ley grassland with arable as a reporting category. It remains unknown whether moving ley grassland from arable would affect the reporting of the SFFS SOC indicator or whether moving ley into improved grassland would affect this category. The NSIS data could be used to inform this issue.

Although a range of alternative reporting units were discussed, they were considered secondary to land use.

- Some variables would be collected as supplementary information as required while others relate to interpretation that may be more appropriate for Tier 2. No consensus was reached.
- Inclusion of multiple reporting requirements would be statistically complex to both design and implement. The capability to address additional reporting requirements, with distinct spatial coverages, could be assessed once a preferred (simple) design was identified, with the option of adding further sampling locations to address specific gaps.
- As we cannot be certain where land uses spatially located are on the ground and as land use can change over time, it was suggested that any stratification used in the design should be independent of land use and vegetation. This could be achieved either by taking a grid-based sample or a stratified random sample with more static strata, such as geographical regions.

2.9 Interpretation of indicator results

Tier 1 monitoring stipulates that there should be some interpretation of the status and change in indicators with respect to impacts of land use, climate change and atmospheric deposition and also, in future, to relate to soil threats. Options to relate monitoring information to these drivers and pressures include selection of specific indicators, collection of information as part of a soil monitoring network, use of contiguous sampling networks, and use of modelled spatial information. There are several listed indicators which will respond to land use, climate change and/or atmospheric pollution. The issue arises in defining the relative importance of each in terms of status and/or change in an indicator (see Table 2.5). Spatial extent of these pressures/drivers could be incorporated into the design phase (such as UKCIP scenarios/deposition maps) thus effectively turning these pressures and drivers into reporting units, as a form of risk area mapping units. This would require some idea of how indicators may respond to these “risks” and ultimately information on action levels and tolerance levels to determine unacceptable levels of change.

Table 2.5 Illustration of possible responses of soil quality indicators (UKSIC selected) to land use, climate change and atmospheric pollution.

UK-SIC Indicators	Pressure / driver					
	Land use	Climate change: temperature	Climate change: rainfall	Atmospheric pollution: N	Atmospheric pollution: S	Atmospheric pollution: metals
Topsoil soil organic matter content/SOC	▓	▓	▓	░	░	░
Soil pH	▓			▓	▓	
Total Cu	▓			░	░	▓
Total Zn	▓			░	░	▓
Bulk density	▓		▓			
C/N ratio	▓	░	░	▓	░	░
Olsen P	▓			░	░	
Total N	▓					
Total Cd	▓			░	░	▓
Potentially mineralisable N	▓	░	░	▓	░	░
Total Ni	▓					▓
Extractable K	▓			░	░	░
Extractable Mg	▓			░	░	░

Notes: Darker shade = direct effects. Light shade = indirect effects (e.g. consequence of soil pH changes) or plant-soil interactions (e.g. increase in plant biomass or quality).

However, as identified by Morecroft *et al.* (2006), impacts of climate change and air pollution on the environment are particularly difficult to identify with a degree of confidence since neither could be feasibly continuously monitored at sampling sites. Therefore possible relationships can only be assessed by using interpolated national data; the uncertainty over these data varies considerably in both space and time. Hypothesis-testing under these conditions to assess likely drivers of change is possible, but it also introduces relatively high levels of uncertainty as there are no direct cause and effect relationships.

Morecroft *et al*. (2006) proposed that comparing trends at sites with contrasting environmental conditions would give more reliable results if there are comparable data on pressures/drivers, for example sites selected to maximise the contrast between air pollution and potential climate change regimes. They have identified a list of soil indicators that would be relevant for this purpose and sites that would be suitable for an equivalent of Tier 2 monitoring. UKSIC may wish to consider whether such interpretation is more appropriate for Tier 2 monitoring. Information that will shortly be available from current research activities across the UK will help to inform UKSIC on the issues surrounding sampling and analysing soils data with respect to attributing the significance of such pressures and drivers, specifically Countryside Survey 2007, NSI England & Wales, NSI Scotland.

The following three sub-sections consider the feasibility of using the data collected in a UK soil monitoring network to report on influence of land use, climate change and atmospheric deposition.

2.9.1 Reporting on the impact of land use

Impacts of land use on soil quality can be established from the statistics produced for the individual land use reporting classes. The issues of reporting by predicted or actual land use were discussed in section 2.8. Using a reproducible protocol, it is technically feasible to collect land use information during the sampling phase of a soil monitoring network. The critical aspect of any protocol is the resolution of the land use information to ensure that all interested land uses can be covered; that is, through detailed field census and/or high-resolution field data that can be aggregated into different land use strata. In this instance, information from the Agricultural Censuses may be considered useful for certain policy issues. Determining the significance of land use change is a retrospective analysis, unless the location and scale of land use change can be determined prior to sampling. Unless the changes are dramatic, there are unlikely to be sufficient sample numbers to assess the significance of individual changes. For example, if there were 400 samples for arable land use in a scheme, and there was a five per cent change in the area of arable, this would result in 20 samples from which to assess the significance of change. This would almost certainly be an insufficient sample for country-level assessments since land use change may be due to numerous different pressures or drivers. It would be more appropriate to determine whether land use change has been significant across monitoring intervals (that is, land use from field observations) and if so, then impacts of land use change becomes an issue for Tier 2 monitoring.

2.9.2 Reporting on the impact of climate change

As yet, no indicators have been designated by UKSIC for climate change, however soil organic carbon could be considered a primary indicator for monitoring this threat (Morecroft *et al*., 2005, Smith, 2004*)*. Various predictions have been made on the potential changes in soil carbon as a consequence of climate change (Smith *et al*., accepted, Smith, 2004) and any monitoring information can be compared against these. However, it must be borne in mind that carbon will also change as a result of other pressures and drivers. Disentangling the relative impacts of climate change may not be appropriate for Tier 1 monitoring. It maybe sufficient at Tier 1 to have an indication that topsoil carbon has changed significantly and thus initiate Tier 2 assessments of stock where investigation of the potential impact of climate change can be carried out using parallel information on the interacting pressures and drivers. Additional caution is advised, at this stage, in the interpretation of Tier 1 topsoil carbon information as this has not been shown to indicate risk to the entire stock of soil carbon

(Smith *et al*., accepted). Again, this may be more appropriate as a Tier 2 exercise. This approach could be supported from existing surveys and monitoring (for example, the NSI for Scotland will be reporting on carbon stock changes by 2009, while both the Countryside Survey 2007 and NSI for England and Wales will be reporting on interactions between different pressures and drivers). In parallel, spatial extent of risk from climate change could be assessed using the modelled UKCIP Climate Change Scenarios from the UK Met Office. UKSIC would need to decide which scenario was most appropriate for the purposes of monitoring at Tier 1, given that the UK Climate Impacts Programme 2007 (UKCIP2007) is about to be released. It is unlikely to be technically feasible, or cost-effective, to continuously monitor climate at sampling locations in a UK soil monitoring network. Contiguous schemes for comparative information would include the Environmental Change Network and the UK Met Office.

2.9.3 Reporting on the impact of atmospheric deposition

Again, it is unlikely to be technically feasible, or cost-effective, to continuously monitor atmospheric deposition at sampling locations in a UK soil monitoring network. Contiguous monitoring of metals, nitrogen, sulphur, and POPs can be obtained from various UK networks if required, with high-resolution modelled spatial information on long-term changes in NHy, NOx, and S available from the UK National Focus Centre. Spatial extent of risk from atmospheric pollution can be determined from the critical loads approach[3]. Risk areas are available from the critical loads approach[4] and could be used in the design phase.

2.10 Sampling

Operational details for sampling would ultimately be provided in technical standard operating procedures (SOPs), which are discussed later. The checklist serves to identify what information will be needed and highlights any knowledge gaps. The workshop boxes highlight discussions on some of these knowledge gaps prior to the tasks dealing with the process map and SOPs.

2.10.1 Sampling design stratification

If required, specification of stratification requirements should be detailed once the primary reporting units, and other reporting or interpretation requirements, have been agreed by UKSIC. This should include details on the appropriate soil and land resource maps to support all phases of the monitoring programme (particularly the design and extrapolation components) and simulation models used for the soil and landscape processes of interest.

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[3] Information available online: http://critloads.ceh.ac.uk

[4] Information available online: http://www.naei.org.uk

Workshop Box 8: Stratification
Based on the outcomes on common reporting (Box 7), the following seven land uses would be the basis for stratification across the UK: heathland, bog, improved grassland, unimproved grassland, broad-leaved woodland, coniferous and cropland, in accordance with the NLUD order and class guidelines. However, the project identified that additional stratification (such as geographical blocks, soil types) maybe required to ensure adequate country-level coverage of these land uses and to address country-level differences in the populations of the soil variables.

In parallel, there are options for using environmental stratifications that have no/minimal relationship to land use.

It was outside the scope of this project to evaluate the many options for stratification in a UK soil monitoring network. The requirements for stratification at the individual country-level should be reviewed once the indicator specifications have been revised to include specific country-level requirements for action-levels and tolerances.

2.10.2 Sampling location

Workshop Box 9: Sampling at a fixed location
A fixed location will be required for the assessment of change in indicators over time and consideration of any effects of land use change. Sufficient site details should be taken to allow relocation after five to 10 years (such as OS coordinates, use of GPS, photographs). In addition, there will be a requirement for a contingency approach to establishing the final sampling locations and numbers in any design scheme since a proportion of sample locations will be inaccessible or lost in any single monitoring event, for example a Foot and Mouth Disease outbreak or land development. A reasonable contingency would be up to 20 per cent of the total sample number, depending on the risk of losing sample locations from contemporary risks.

2.10.3 Sub-sampling/sampling support

To be directly comparable with specific action-levels, there needs to be consideration of two sub-sampling regimes to ensure that information is comparable to currently available datasets. The sub-sampling would follow the methods of the Soil Survey England and Wales handbook (Hodgson, 1976) with 25 sub-samples per sample taken by auger. The second involves a single core from a set location following the Countryside Survey methodology (Black *et al*., 2000). Consideration may need to be given to other country-level schemes (such as NSI for Scotland and Northern Ireland) to achieve comparability with recent repeat sampling exercises.

Workshop Box 10: Sampling support

Harmonisation of sampling methodology is essential for cross-UK data compatibility and comparison of results. In addition, sampling at each site (sampling support/sub-sampling) needs to be comparable with pre-existing indicator requirements (such as SFFS, Soil Survey England and Wales handbook with 25 sub-samples per sample taken by auger).

We could harmonise on the sampling methods of the Soil Survey England and Wales handbook (Hodgson, 1976) with 25 sub-samples per sample taken by auger at four-metre intervals over a 20 x 20 m area. Although this approach seems sensible there was uncertainty about sampling for horizons, in terms of sub-sample numbers required. The current sampling of the NSI is comparing different methods of collecting samples which would give some indication to the variability and help to inform the requirements for sampling support.

2.10.4 Sampling depth

It is assumed that all soil sampling will be carried out on the topsoil with the predominate depth of 0 to 15 cm, using standard sampling procedures in assessing topsoil depth. Consideration is also required for the indicators which require 0 to 7.5 cm samples, such as grassland soils for pH, potassium, phosphorous and magnesium. Any resourcing assessments should consider the costs of taking samples from both depths from all grassland soils[5] with the assumption that these must be separate samples to ensure statistical validity of the resultant information.

Workshop Box 11: Sampling depth

Should we harmonise on sampling 0-15cm uses in all countries, with 0-7.5 cm for certain land uses?

There was common agreement on a unified sampling depth of 0-15 cm and acknowledgement that there would need to be a sample of 0-7.5cm in grasslands for compatibility with existing surveys (such as Northern Ireland).

There was discussion on the need for horizon-based sampling with the suggestion that a minimum sample should be a B horizon bulked sample (to the bottom of B horizon or depth if possible, such as 75 cm) at all sites. Sampling could include a surface pit and with augering to depth. However there was no consensus on how to sample or to what depth. Section 5 will assess whether there are sufficient robust protocols to include this at present.

2.11 Sample Analysis

Analytical methods for most indicators have been set out in UKSIC reports (in particular Environment Agency, 2006a). These methods are listed in the individual indicator specification tables, Appendix B. Approximate costs for some methods were also provided in the Environment Agency report. An accurate costing could only be derived once a preferred design was linked to exact measurement details (such as standard

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[5] This would only be required for the auger sample; 0 – 15 cm and 0 – 7.5 cm in grassland

operating procedures, quality control and quality assurance) and staffing capacity (availability and skill).

2.12 Supplementary information

Table 2.6 lists current requirements for supplementary information. This list should be completed once the design has been finalised with requirements for specific indicators versus supplementary information. Areas to be considered whilst identifying supplementary information requirements include data from other sources, initial site characterisation and detailed land use information.

Table 2.6 Supplementary information required for UKSIC indicators

Indicators	Specific land use information	Additional soil info.	Other
SOC	Arable/ grassland/land classes	Bulk density for future. Clay content. Soil type	Rainfall: accumulated annual ppt, geological info, climate
Cu		pH, clay, SOC, CEC, soil texture class	
Mg + K	Arable-forage / vegetables / grassland		
Cd			
Bulk density	Arable / improved grassland / permanent grass / heath	Mineral / Calcareous / Peaty soil types	
Olsen P	Arable-forage / vegetables / grassland		
pH	All land uses	Mineral / Calcareous / Peaty soil types	
Ni		pH, clay, SOC, CEC, soil texture class	
Zn		pH, clay, SOC, CEC, soil texture class	
C:N	All land uses		
Potentially mineralisable N			

Workshop Box 12: Supplementary information

Bulk density is essential supplementary information, as well as any information required to establish action levels for individual indicators (such as texture or rainfall classes). Suggested ancillary data included soil types, altitude, and environmental protection schemes. Indicators of climate change were considered but there was uncertainty over indicators that would effectively reflect a change in climate, such as responses to rainfall and so on. Future monitoring should also be used to gain baseline information on proposed indicators to further their development.

2.13 Archiving

For soil archiving to occur as part of a soil monitoring network there is a requirement for soil archives to be established within each devolved administration, as well as a complete national archive (partly a risk minimisation strategy). Soil samples would therefore need to be split, with half retained by the relevant devolved administration and half retained within the national archive. The splitting would require a standard protocol to ensure that each sample was representative of the original sample. The projected timescale was set at 10 years for these archives. This information can be used to estimate resourcing requirements and costs. It does not reflect any fixed term commitment to the archives from the UKSIC partners. Initial requirements for archiving include sufficient space to hold the archive as a single unit in a secure environment, for example protected from fire, water damage (no sprinklers) or unauthorised entry. The soils themselves will have differing requirements for archiving based on maintaining a capacity to resolve repeat sampling issues, such as quality control in repeating methods, resolving different methodologies and flexibility for novel indicators in the future. Table 2.7 summarises current and potential archiving requirements for a UK soil monitoring network.

Table 2.7 Archiving for a UK Soil Monitoring Network

Indicator	Archiving	Resources	Indicators	Unknowns
Archiving for current list of UKSIC indicators	Air dried sieved soil	Sufficiently large enough labelled tight containers	SOC, pH, Cu, Zn, Cd, Ni, C:N, Olsen P, total N, ext Mg, ext K	Potentially mineralisable N
Potential archiving for "future-proofing"	Frozen sieved soil samples (e.g. at -80^{o}C)	Small inert containers in a reliable -80^{o}C freezer	Soil biological indicators based on DNA extractions	Longevity of this sample to 10 yrs
Potential archiving for "future-proofing"	Frozen intact soil cores	Small inert containers in a reliable -80^{o}C or -10^{o}C freezer	Organic contaminants	Longevity of this sample to 10 yrs
Potential archiving for "future-proofing"	Freeze-dried sieved soil samples	Small inert containers stored in a dark, cool and dry environment	Biochemical characterisations (e.g. PLFA)	Longevity of this sample to 10 yrs
Potential archiving for "future-proofing"	Freeze-dried soil extracts	Small inert containers stored in a dark, cool and dry environment	Biochemical characterisations (e.g. PLFA)	Longevity of this sample to 10 yrs

Workshop Box 13: Sample archiving
Agreement that the minimum requirement for archiving is an air-dried sieved sample, although it would also be a good to have a frozen sample. Keeping samples for 10 years would be sufficient for validating analytical methods between monitoring cycles. If new methods become available these should be applied to historical samples, therefore an archive needs to be as indefinite as possible, although it might not be necessary to keep all samples from every cycle. Archiving needs to be linked to data management.

A central archive would be more efficient and cost-effective than four devolved archives, but there were concerns about access to samples, who would pay for joint storage facilities, and who would control access to the samples. For security, duplicate archives are needed. One possibility would be an archive of all samples in each of the four countries. There are also possibilities to use existing international archives. Access permissions would need to be clarified at the outset. Whether or not there is a joint store, there needs to be a Memorandum of Understanding between countries to determine how the archived samples could be accessed and used.

2.14 Data management

There is a UKSIC requirement for digital spatially explicit soil databases in each devolved administration but not a complete soil database in a single location. These databases must include all information collected in the field, that is, soils data plus site characterisations and supplementary information. This would include resolution of grid coordinates; GB National Grid coordinates for all the UK sites will require conversion from the Irish Grid coordinates used in Northern Ireland.

Implementation must consider the staffing and recurrent costs required to set up and maintain these databases in addition to establishing the capacity to analyse data for all indicators from the first sampling. It would also be appropriate to utilise these databases as central archives of information on the design and implementation stages that may be required in subsequent samplings. Given the current capacity to access databases on-line, it may be more cost effective and scientifically rigorous to maintain the soils data as a single unified UK database with access provided on-line as required or on request.

Workshop Box 14: Data management

There was insufficient time to address data management at the workshop but it was recognised that this would be integral to effective monitoring including archiving and reporting. Any system would need to be compatible with existing and future end-user initiatives (such as INSPIRE).

2.15 Statistical analysis

Statistical analysis should be adequately resourced for each indicator of interest. The statistical routines required to produce the required reporting outputs should be documented along with all other monitoring protocols. It would be both more cost effective and scientifically rigorous for the statistical analyses for the main reporting to be carried out as a unified exercise – that is, a single group analyses all data, from a single unified UK database, to produce the required statistics for all reporting classes and action-levels.

2.16 Reporting of results

For each monitoring event, the requirements for dissemination must be determined in consultation with the relevant end-users. In the first instance, it may be expected that a summary report would be produced for each of the devolved administrations based on the outcomes of the statistical analyses. For Tier 1 monitoring in particular, this report should detail which indicators deviate from the action-levels, indicating that Tier 2 monitoring should be considered.

2.17 Checklist conclusions

The development of this checklist established key details to assist in designing options for a UK soil monitoring network but it is not a completed document. It proved useful in identifying technical and policy uncertainties in requirements for a monitoring scheme that were discussed and, where possible, resolved at the stakeholder workshop. The workshop resulted in agreement on common indicators, reporting units and protocols to support the designing options and help to address comparability across the UK between country-level sampling schemes. A key priority remains the completion of the indicator specifications, in particular the requirements for quality measures (with tolerances) and action levels.

It is envisaged that the checklist should continue to be developed as the requirements for a UK soil monitoring network are refined. If the checklist is maintained it will serve as written historical record and in so doing ensure that future monitoring will have an invaluable reference source to return to.

3 Designing options for a monitoring scheme

3.1 Introduction

Monitoring is defined as “collecting information on soil through repeated or continuous observation in order to determine possible change in soils”. It is useful to consider the three categories defined by de Gruijter *et al*. (2006) as these have implications in developing the options for a UK soil monitoring network.

- **Status / ambient monitoring.** To characterise or quantify the status of soil and follow how it changes over time, such as topsoil carbon content in different land uses. The sampling scheme should therefore allow for the repeated efficient estimation or prediction of the soil quality indicators.
- **Trend / effect monitoring.** To assess the possible effects of pressures or drivers on soils with the objective to determine not only status but also whether a change was caused by a specific event, for example the effect of a change in land use policy on topsoil carbon content. The sampling scheme should therefore provide statistical validity and sufficient power of hypothesis testing.
- **Regulatory / compliance monitoring.** To determine whether soils are failing to meet set standards or targets. For example, are soil metal levels greater than the limits set in the sludge regulations? The sampling scheme should therefore provide statistical validity and acceptable error rates in classifying the soil according to the set criteria and limits.

The purpose of a UK soil monitoring network requires that the ultimate design option for a UK network can address all three of the above aspects of soil monitoring. The following sub-sections describe the following:

- Identification of a number of alternative options for the soil monitoring scheme using the expert judgement and experience of all members of the consortium based on the agreed objectives, quality measures and constraints from the checklist and assessment of these options in a brainstorming session to identify the most promising four or five alternatives.
- Identification of datasets that could be used to assess these options.

3.2 Identification of most promising options

Potential sampling scheme options were assessed in a brainstorming session attended by members of the project team. Four broad questions relating to the objectives, quality measures and constraints detailed in the checklist were considered.

- Do we use model-based or design-based methods?
- How do we manage our ignorance (at the onset of the survey) about the temporal variability of most of the indicators?

- How do we manage the differences in variability between different soil landscapes of the UK?
- How do we manage the differences between indicators?

The following sections detail the outcomes of this session.

3.2.1 Model-based and design-based methods

Model-based and design based methods are alternative statistical approaches to developing a sampling scheme for a UK soil monitoring network with different strengths and limitations, depending on the objectives, measures and constraints. In general, model-based methods are best suited to providing local estimates while design-based are better suited to providing estimates of overall means; but other factors are important in this choice (c.f. de Gruijter *et al*., 2006). Design-based methods require some sort of randomised sampling, while model-based methods typically entail systematic sampling (on a grid, for example).

Model-based. In model-based approaches to sampling we assume that the variation of the properties that we are interested in arises from a random process that we can model statistically. It is this assumption, rather than randomisation of the sampling scheme, that provides the basis for subsequent analysis of the data. We can therefore set out our sampling points in a systematic way, which is often most appropriate if our objective is to map the spatial variation of the variables under investigation. We can also optimise the sampling scheme, for example minimising estimation variance of the estimated means of the reporting classes. This optimisation is based on some estimate of the underlying model (perhaps from reconnaissance information). Such a model is the variogram, which is widely used in geostatistical sampling and estimation. On the basis of the model we can, for example, design a sampling scheme that ensures that the mean estimation variance of a property is minimised.

One type of sample selection for this type of scheme is to use a regular grid (an example being the National Soil Inventory in England and Wales based on a 5 km grid) or a spatial coverage sampling scheme, which aims to ensure an even coverage. A similar pattern would be created if the mean estimation variance is minimised. If we sample in this way then we must also include some extra sampling points to ensure that the model that we compute from our data (the variogram, for example) describes variation over short distances well.

A more sophisticated approach recognises that the uncertainty of our model-based estimates arises partly from the variation of the properties that we are studying, and partly from uncertainty in the model that we compute from the data used for estimation. We therefore design a sample scheme which aims to ensure both good spatial coverage and that we compute a good model from the resulting data.

An option with this second type of sample selection is to divide sampling into two phases, where the second phase may be adapted using information from the first. This is not fully adaptive sampling, but has some advantages over sampling in a single phase (c.f. Emmett *et al*., 2007).

Design-based. In general, for a design-based method the samples are selected using random sampling. These samples can then be used to give an unbiased estimate of the mean and variance, provided the probability of including each unit in the sample is known (and none of these are zero). The variance of the mean can be greatly reduced if, instead of sampling from the whole population at random, samples are drawn from sub-populations (strata). As well as wanting to reduce the variability of the estimates of the mean, we would also want to reduce the travel time, and hence cost. This can be achieved using clustered sampling where the initial selection of sampling units is random within strata, then the actual sampling points are selected within these sampling units. Countryside Survey utilises this approach with five sampling locations within 1 km squares, which were selected from the ITE Land Classification, an environmental stratification of Great Britain[6].

Adaptive sampling, which can be applied to both model and design-based options, is one solution to the problem that when we first set out a monitoring scheme we do not have sufficient information on the spatial variation of the change in the variables that we want to monitor, and only have information on the current status. An adaptive sampling scheme could adjust to take account of emerging information on the variability of change. There is limited information available on change in soil properties over a large spatial scale, and this is over relatively long time intervals (*c*. 15 years). Given this, there is no scope to make a meaningful assessment of the value of adaptive sampling schemes at present, so they were not considered further. However, it will be important to consider adapting the sampling scheme as information becomes available from the later re-sampling phases.

As a result of discussions, two options for model-based schemes were proposed and two for design-based schemes:

- ***Model-based, systematic (grid) sampling***. The basic strategy is to sample on a grid, but with additional short distance points added to ensure (i) that some rarer classes receive adequate sampling and (ii) to ensure that we have observations to model the random variation. The grid is modified to ensure adequate coverage of all target land cover classes, and to include some points to permit modelling the variation of the target properties over short distances. The grid was optimised given a variance model for soil organic carbon. It was then evaluated for all indicators, as described below.
- ***Model-based, optimised sampling***. A scheme that minimises the estimation variance for reporting class means, given that this variance will arise from both spatial variability of the soil properties of interest, and error in the statistical model computed from the data. The overall sample design is optimised to minimise the estimation variance of mean values of the soil properties within land cover classes. We account for both the variability of the properties and the uncertainty in the statistical model in this optimisation.
- ***Design-based, stratified random sampling***. Stratification by country and some form of habitat classification with single point sampling. The sample points are distributed at random within strata. The strata used were geographically defined blocks within the land cover classes.
- ***Design-based, cluster stratified random sampling***. Stratification by country and some form of habitat classification with clustered sampling. Stratified random sampling points are selected, and then additional points are added at random within a relatively short distance. This reduces the total distance to be travelled.

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[6] Countryside Survey is best described as a stratified random sub-sample of a systematic sample. Due to computing limitations at the time of design, sample squares were selected from a 15 km grid covering GB. The systematic element in this design will result in conservative (i.e. tending to be too large) estimates of variance under some quite general conditions that are likely to hold for such a large-scale sampling operation

3.2.2 Managing ignorance of temporal variability of indicators

A monitoring scheme must be designed to estimate change over time, but most of our spatial soils data are from a single survey period. Different options exist to tackle this problem within both the model-based and design-based frameworks, and these were discussed. Information available to the project (Table 3.1) means that the only information on the indicators' 'change in soil organic carbon' and 'change in soil pH' will be over the time intervals of 15 to 20 years. Several studies have been made to recommend the length of interval between sampling events within sampling schemes for soil carbon (Saby and Arrouays 2004, Smith *et al*., 2004). The consensus appears to be that the minimum sampling interval should be five years (as no changes will be detectable if sampled more frequently) and that 10 years would be a reasonable interval in practice (c.f. Miller *et al*., 2001). However these details are based on simulated or small-scale data and further temporal information from large-scale surveys and monitoring is required to establish whether these estimates are accurate.

As mentioned above, in both model-based and design-based sampling it is possible to employ adaptive sampling methods that will adjust sample effort as we learn about variability. In the design-based case there are well-established approaches (for example, see Thompson and Seber, 1996), and there is recent research on adaptive sampling in the model-based case (for example, see Marchant and Lark, 2006). However, we decided that while the consideration of adaptive changes to the monitoring design should be part of the protocol, no meaningful assessment of their benefit can be made from currently available data. It was decided therefore that this project would estimate state and change for soil organic carbon (as information is available). In practice it might be necessary to start off with two repeat samplings, five to 10 years apart, and then possibly move to adaptive sampling as we gather more information on the variability over time.

3.2.3 Managing differences in variability between different soil landscapes of the UK

It is very likely that the indicators will differ in their spatio-temporal variability between different soil landscapes. If the quality of our information is to be uniform, the sampling must respond to these differences. We might, for example, sample more intensely in more variable landscapes than in others. Some discussion was had of how to manage these differences. The difficulty in the context of the present design question is that many indicators are of interest and very detailed adaptation to differences in variability of all these indicators is not technically feasible. It was noted that the variation in SOC across Scotland is very different to that in England, Wales and Northern Ireland, and that this difference is also apparent for other indicators. It was decided that, initially, we would design schemes for the four countries separately as they have such different spatial variability, but that the procedures followed to arrive at the designs would be the same for all countries.

It is important to note that change in an indicator may or may not be related to status in an indicator. Consider metals in soil, for example. Their variation at national scale is largely determined by geology, but change may depend on pollution, leaching and so on, and so the spatial variation of change need not look much like the spatial variation of status. As a consequence, a sampling scheme that is good for resolving a pattern of variation in metal driven by geology is not necessarily suitable for resolving a pattern of variation in change driven by other processes. Since the UK is the one of the first regions to have change information on soils over large spatio-temporal scales, this project is one of the first opportunities to explore these issues.

3.2.4 Managing the differences between indicators

Some indicators are likely to be more variable than others and, as noted above, their variation will change across landscapes, requiring more intensive sampling. However, it is not feasible to monitor each indicator on a different sampling scheme, so a unified scheme, adequate for all key indicators must be found. It was decided that, as SOC was the only indicator that was consistently identified as necessary to address most policy issues, SOC would be chosen as the indicator for which to optimise the design of the monitoring scheme for both status and change. The design options obtained for SOC would then be investigated for the other indicators to assess how well the other indicators could be measured.

3.2.5 Consensus from option identification

Do we use model-based or design-based methods?

As a result of discussions two options for model-based schemes were proposed and two for design-based schemes, a **model-based** with systematic sampling or optimised sampling and a **design-based** with stratified random sampling or cluster stratified random.

How do we manage our ignorance (at the onset of the survey) about the temporal variability of most of the indicators?

The consensus appears to be that the minimum sampling interval should be five years (as no changes will be detectable if sampled more frequently) and that 10 years would be a reasonable interval in practice (c.f. Miller *et al*., 2001).

How do we manage the differences in variability between different soil landscapes of the UK?

It was decided that, initially, we would design schemes for the four countries separately as they may have different spatial variability but that the procedures followed to arrive at the designs would be the same for all countries.

How do we manage the differences between indicators?

It was decided that as soil organic carbon was the only indicator that was consistently identified as necessary to address most policy issues, this would be chosen as the indicator for which to optimise the design of the monitoring scheme for both status and change.

3.3 Available test datasets

The ability to test the statistical performance of each scheme was governed by the availability of spatial and temporal data on the indicators to test each option. Table 3.1 illustrates the availability and source of national-scale spatial and temporal data within the UK to support development of each scheme. Although there are numerous local and regional soils datasets within the UK (Emmett *et al.,* 2007a), UK or national reporting was a key stakeholder requirement and therefore national spatial coverage of soils data was most appropriate for the statistical approaches. Where no data currently exist, a reasonably simple design giving adequate spatial coverage (through stratification or use of an approximate grid) should provide baseline information about status, which can then be used to reassess sampling schemes. Information being collected for the NSIS and Countryside Survey 2007 would be useful in this context.

Table 3.1 National scale data available to the project team at March 2007

	England		**Wales**		**Scotland**		**Northern Ireland**	
	Space	Time	Space	Time	Space	Time	Space	Time
Soil carbon	NSI$^{E\&W}$ CS	NSI$^{E\&W}$ CS	NSI$^{E\&W}$ CS	NSI$^{E\&W}$ CS	NSIS CS	CS	NSI^{NI}	▨
Soil pH	NSI$^{E\&W}$ CS	NSI$^{E\&W}$ CS	NSI$^{E\&W}$ CS	NSI$^{E\&W}$ CS	NSIS CS	CS	NSI^{NI}	▨
Total Cu	NSI$^{E\&W}$ CS	▨	NSI$^{E\&W}$ CS	▨	NSIS CS	▨	NSI^{NI}	▨
Total Zn	NSI$^{E\&W}$ CS	▨	NSI$^{E\&W}$ CS	▨	NSIS CS	▨	NSI^{NI}	▨
Bulk density	▨	▨	▨	▨	▨	▨	NSI^{NI}	▨
C to N ratio	CS	▨	CS	▨	CS NSIS	▨	NSI^{NI}	▨
Olsen P	NSI$^{E\&W}$ CS	▨	NSI$^{E\&W}$ CS	▨	CS NSIS*	▨	NSI^{NI}	▨
Total N	CS	▨	CS	▨	NSIS CS	▨	NSI^{NI}	▨
Total Cd	NSI$^{E\&W}$ CS	▨	NSI$^{E\&W}$ CS	▨	NSIS CS	▨	NSI^{NI}	▨
Potentially mineralisable N	▨	▨	▨	▨	▨	▨	▨	▨
Total Ni	NSI$^{E\&W}$ CS	▨	NSI$^{E\&W}$ CS	▨	NSIS CS	▨	NSI^{NI}	▨
Ext. K	NSI$^{E\&W}$	▨	NSI$^{E\&W}$	▨	NSIS	▨	NSI^{NI}	▨
Ext. Mg	NSI$^{E\&W}$	▨	NSI$^{E\&W}$	▨	NSIS	▨	NSI^{NI}	▨

Notes: Time and space data now available for Scotland
NSI$^{E\&W}$ National Soil Inventory for England and Wales held by Cranfield University
CS Countryside Survey held by the Centre for Ecology and Hydrology
NSIS National Soil Inventory for Scotland held by the Macaulay Institute.*Extractable P
NSI^{NI} National Soil Inventory for Northern Ireland held by Agri-Food and Biosciences Institute

During the brainstorming session, the datasets (Tables 3.1) that would be used for the detailed assessment of the different sampling approaches were identified. National-scale surveys where SOC has been measured and the data are available to the project consortium are: the National Soil Inventories of England & Wales, Scotland and Northern Ireland and Countryside Survey. As these surveys are not all sampled in the same way and the methods of analysis are different it was decided it was best to keep the data for the four countries separate. This meant that the only amalgamation of data that was to be carried out was between the Countryside Survey and the National Soil Inventories of England & Wales and Scotland. Table 3.2 provides a description of soils information available from existing national-scale soil schemes. Although there are other substantial data sources within the UK, these have not been included in this instance since they address specific land use types (such as Biosoil, RSSS or British Woodland Resurvey).

SNIFFER project LQ09 (Emmett *et al*., 2007a) identified that the only data available for urban soils is that held by BGS (G-BASE), although the recent (June 2007) Environment Agency UK soils and herbage survey (UKSHS) may also be relevant. If urban soils were to be considered in a UK soil monitoring network then the BGS datasets, in particular, must be analysed for information on the variability of urban soils. However, urban soils are notoriously complex and unlike the data analysed as part of this design exercise, therefore any analysis of G-BASE would require input from the expertise within BGS to resolve issues rather specific to sampling urban soils representatively, such as black carbon (for example soot deposits, see Rawlins *et al*., 2008).

3.4 Reporting classes

Our objective, which would provide a basis for the comparison of design options, was to report mean values of soil indicators for land use classes by country. We call these land use classes "reporting units", since our target is to report mean values of indicators for each class. It was therefore necessary to agree on a classification to use for assessing the design options. In the meeting it was stressed that whichever system is chosen, all the data points in the four datasets need to able to be classified within that system, and that the classification also needs to be mapped to a reasonable scale across the UK (the data for this map must be available in digital form, say for each 1 km square). It was assumed that one of the classification sets identified in the checklist would be chosen and these were investigated after the meeting to assess their suitability. It was clear that the identification of this classification would probably be an iterative process as the data providers need to assess how easily their data could be classified.

Classes from level 1 of LCM2000 (Land Cover Map) were used as the reporting units as it is available in a spatial form across the whole of the UK. LCM classification is almost entirely compatible with the NLUD Land Cover classification with cross-referencing tables available from the NLUD website. The only exceptions are ley grassland and bracken. Ley grassland appears under improved grassland for NLUD Land Cover and under arable for LCM2000. Bracken appears under semi-natural grassland in LCM and under heath & bog in the NLUD classification.

The dominant class on a 1 km grid was chosen as most appropriate and the data obtained from the Centre for Ecology and Hydrology (CEH). The data was provided at level 2 (24 classes), and so was reclassified into the 16 classes of level 1. These reclassified data were sent out to all data providers along with a list of statistics required for all possible indicators for each country. This exploratory analysis was carried out for each available dataset to enable a performance assessment of the individual design options. Given the sparseness of soil data within some of the LCM2000 level 1 classes, subsets of the classes were agreed with the Project Board for use in the assessment.

The classification for the whole of the UK (from LCM2000) was converted to a grid reference and value to establish a model of variability for every indicator for each of the classes within each country. A statistical model of the variability of each indicator was derived. These models could then be used to simulate data with variability comparable to the real data. Data could be simulated at sample points selected according to the different sampling schemes, and then used to compute the variance of the estimates of the reporting class means achieved by each scheme. This was done over 100 realisations (100 sets of sample points drawn according to the particular randomisation procedure). Since the simulated data would come from a common model, these variances would be comparable between sampling schemes. In addition, travel distances between the sample points in each sample scheme were calculated as a basis for comparison of their logistical costs.

Table 3.2 Current monitoring schemes covering a range of classes

Current Monitoring Scheme	Sample dates	Sample design	Soil properties	Area Covered	Scheme Comments
Countryside survey	1978, 1998, 2007	Stratified random sample from 15km grid intersections	Topsoil depth 0-15 cm for most properties. 1978: pH and LOI. CS2000: pH, Loss on Ignition (LOI), Total C and N, Olsen-P, Total Cd, Cr, Cu, Ni, Pb, V, Zn, Hg, As, bacterial counts, BIOLOG, invertebrate taxa, Range of PAHs and PCBs on subset of samples. CS2007 bulk density, pH, LOI, Total C and N, Olsen-P, mineralisable N, Total Cd, Cr, Cu, Ni, Pb, V, Zn, Hg, As, invertebrate taxa, micriobial biodiversity (tRFLP).	England, Scotland Wales	Scheme based on representative sampling of ITE land classes (currently 42 across UK). Original survey = 256 1 km squares x 5 soil sampling locations (max. 1280 samples). For 1998 (CS2000) reporting was by environmental zones and JNCC broad habitats for UK, England and Wales combined and separately for Scotland (Black *et al.*, 2000). Sampling in 2007 increased to ~600 1 km squares (max. ~ 3000 samples).
National Soil Inventory England & Wales	c.1978 - 1983. Repeat sampling for SOC on subset during 94, 95 and 2003	5 km square intersections	Horizon: colour, texture, structure, moisture, porosity, roots, stones (shape, number and size) carbonates, nodules. Topsoil depth 0-15 cm; soil pH in water, SOC, particle size distribution, available K and Mg, available P, extractable Cd, Co, Cu, Pb, Ni, Zn, total Al, Ba, Cd, Ca, Cr, Co, Cu, Fe, Pb, Mg, Mn, Ni, P, K, Na, Sr and Zn.	England, Wales	Not designed to be used for the individual countries, but since it is a grid-based design it can be divided easily between the two countries. Any reporting classification can be applied (and means and variances computed) showing the flexibility of a grid-based design. Some classes, however, may be underrepresented, for example in Wales only 15 of the 770 original NSI sites in Wales fall in land cover classes 8 and 15, so any estimate of the mean for these classes will not be very precise, also some classes are not represented at all. The latter maybe because there is very little land under that land cover in Wales or the distribution is such that it is not captured by a 5km grid.
National Soil Inventory Scotland	Start 1978 and finish 1987	10km grid intersects with additional morphological information at 5km intersections	Depth to top of sample; Depth to base of sample; LOI; % International sand, silt clay; % of USDA or BSTC sand and silt; Ca; Mg Na; K; Exch acidity; Sum of cations; Base saturation; pH in water; pH in Calcium chloride; Total C; Total N; C/N ratio; Organic matter; Total P; Sample Batch Identification; In addition to soil parameters measured for NSIS 1, topsoil horizons were later analysed for Ca; Na; K; Mg; Cu; Zn; Fe; Mn; Al; P; Ni; Cd; Cr; Co; Pb; Sr; Mo; Ti; Bi. NSIS_2 (2006-2008) includes top horizon and topsoil (0-15cm) analyses.	Scotland	As for NSI England and Wales, any reporting classification can be applied since it is a grid-based design. Some classes, however, may not be represented.

Current Monitoring Scheme	Sample dates	Sample design	Soil properties	Area Covered	Scheme Comments
National Soil Inventory (Northern Ireland) AFBI pits 5K	1988-97	5 km square intersections. Survey was restricted to agriculturally important areas, generally below 200m altitudes.	Topsoil 0-15cm (0-7.5cm in grasslands); pH (water), Olsen-P, available K & Mg; total P; exchangeable Mg, K, Ca, Na; CEC; total N &C; LOI; % sand, silt, clay, stones; bulk density & total porosity; Qvt5, Qvt10, Qvt40, Qvt200 & Qvt1500; plant-available water; air capacity; total (aqua-regia digest) P, K, Mg, Ca, Fe, Na, Cd, Cr, Co, Cu, Pb, Mn, Mo, Ni, and Zn (518 A-horizon samples only). Also 0.05M EDTA-extractable S, Ca, Fe, Na, Cd, Cr, Co, Cu, Pb, Mn, Mo, Ni, and Zn (167 A-horizon samples only).	Northern Ireland	As for NSI England and Wales, any reporting classification can be applied since it is a grid-based design. Some classes, however, may not be represented.
National Soil Inventory (Northern Ireland) AFBI 5K 2005	Oct 2004 - Mar 2005	5 km square intersections. Same as sample locations from AFBI 5K PITS 1995 scheme plus additional fill-in samples to complete the 5K grid.	Topsoil 0-15cm (0-7.5cm in grasslands); pH (water and CaCl2), Olsen-P, total-P; available K, Mg & S; total N & C; LOI; % sand,silt,clay (to come); % stones; bulk density & total porosity; Qvt5; air capacity.	Northern Ireland	As for NSI England and Wales, any reporting classification can be applied since it is a grid-based design. Some classes, however, may not be represented.
Geochemical Baseline Survey of the Environment	Started in 1968, should be completed in 2015	Systematic grid of 1 per 2 km2.	Total concentrations of Na2O, MgO, Al2O3, SiO2, P2O5, K2O, CaO, TiO2, MnO, Fe2O3, Sc, V, Cr, Co, Ba, Ni, Cu, Zn, Ga, Ge, As, Se, Br, Rb, Sr, Y, Zr, Nb, Mo, Hf, Ta, W, Tl, Pb, Bi, Th, U, Aa, Cd, Sn, Sb, Te, I, Cs, La, Ce, soil pH and Loss on Ignition (as an indicator of organic matter).	England, by 2015 Scotland Wales Northern Irealand	Grid-based design, so any reporting classification can be applied. Problems may arise due to the length of time of the survey. Also soil samples ignore the top 5cm.

Notes: Adapted from SNIFFER LQ09 (Emmett *et al*. 2007a)

3.5 Performance of individual options

3.5.1 Introduction

The aim of this task was to derive relationships between the survey effort (sample size and distance travelled to collect samples) and the quality of estimates of status and change in the indicators, where information was available, for the four scheme options. In addition, other considerations that might influence the choice of sampling scheme were systematically set out. This information could then be used to allow the adequacy of the alternative design options to be evaluated for each available indicator and to compare the different options.

Therefore the main components of this task were:

- Development of monitoring schemes to be assessed.
- Estimation of spatial models for each variable from existing surveys.
- Simulation of each variable at the site of each observation in the proposed monitoring schemes.
- Calculation of the estimation variance for each proposed scheme.
- Calculation of distance that must be travelled to complete each phase of the monitoring scheme.

3.5.2 Approach

In order to complete this task, some initial decisions were necessary. The first was to identify the basic survey objective on which sampling schemes were to be compared. This was defined as the estimation of mean values (status or change) for land-cover classes within England, Wales, Scotland and Northern Ireland separately.

The second decision was to identify a working quality measure for use in basic assessments. We identified the estimation variance of the land-cover class means, on the basis that this is a widely established quality measure, with a sound theoretical basis and comparable between sampling options.

The next stage was to compute, for each of the indicators, the value of this quality criterion (estimation variance of the land-cover class mean) for each of the land-cover classes under each of the four scheme options. The estimation variance of each soil indicator was assessed by testing each sample design upon simulated data. The models used to generate these simulations were fitted to data from existing surveys of the soil indicators.

Within each sampling option we considered three total sample sizes across the UK. In order to ensure comparability between the sampling options we used the same sample size for each option. A travelling salesman algorithm was applied to calculate the distance to be travelled in order to collect all of the samples (this finds the shortest distance that must be travelled to visit a given set of sample points). Note that the route around the points represents a single journey (that is, we assume that breaks in sampling are taken at local centres and do not involve travelling substantial distances).

Status of SOC and change in SOC were regarded as the main canary indicators. Therefore more detailed analyses of the effectiveness of the schemes were carried out for these indicators. The more detailed analyses also reflected the relatively complicated statistical distribution of soil organic carbon over the UK.

3.5.3 Methods

In this section we describe how the four scheme options were assessed. First we consider general constraints that applied to all options (to ensure comparability in their coverage of the land cover classes). Second, we explain how sampling schemes under the four options were generated. Third, we explain how the schemes were tested. This was done by (i) modelling the spatial variability of indicators in as much detail as possible, (ii) using this model to simulate realistic data at the sample points and (iii) computing statistics from the simulated data.

Design of monitoring schemes

In all cases our basic task for comparing sampling schemes is to estimate mean values of soil indicators by land cover classes for England, Wales, Scotland and Northern Ireland (both status and change, where suitable data were available). The land-cover classes assessed in each country are shown below (Table 3.3). The basic classification is the Level 1 legend classes of the CEH LCM2000, but we have used a subset of these in each country. The subsets were selected because (i) adequate data were not available for all classes in each country and (ii) a reasonable number of sample points could not be allocated to all classes under our proposed sampling schemes without undue distortion (since some of the classes are relatively rare).

We used three overall sampling intensities across the UK: 1000 (S1), 2000 (S2) and 4000 (S3). A minimum of 10 sample points in any land cover-country combination was stipulated, otherwise points were allocated proportionally to the area of the class across UK. The choice of 10 sampling points was more or less arbitrary; it was chosen so as to avoid substantially distorting the allocation of points from proportional allocation. As noted above, we exclude some rarer land cover classes (such as broad-leaved/mixed woodland in Northern Ireland).

As identified in section 3.2.1, the sampling options considered were as follows:

- ***Model-based, systematic (grid) sampling***. The basic strategy is to sample on a grid, but with additional points added to ensure (i) that some rarer classes receive adequate sampling and (ii) to ensure that we have observations to model the random variation.
- ***Model-based, optimised sampling***. The sample points were selected to minimise the estimation variance of the model mean for the Land Cover classes, given that contributions to this variance come both from spatial variation of the soil, and in uncertainty of the spatial model (the variogram) that we compute from the data.
- ***Design-based, stratified random sampling***. The sample points are distributed at random within strata. The strata used were geographically defined blocks within the Land Cover classes.
- ***Design-based, cluster sampling***. Stratified random sampling points are selected, and then additional points are added at random within a relatively short distance. This reduces the total distance to be travelled.

The sampling schemes were applied to generate proposed samples at each of three sampling intensities S1, S2 and S3 (1000, 2000 and 4000 respectively) across the

United Kingdom. However, the cluster sampling (design-based) was only applied at the largest sample intensity, S3.

Table 3.3 Land cover classes used for assessment within each country with proportional allocation based on area of land cover class in each country.

Country	Land cover class		Count	S1	S2	S3
England	5	Bog	1023	10	20	40
England	6	Dwarf shrub heath	2403	10	20	40
England	8	Broad-leaved / mixed woodland	6869	26	53	106
England	9	Coniferous woodland	2464	10	20	40
England	10	Improved grassland	39698	153	306	612
England	11	Semi-natural grass	10298	40	79	159
England	14	Arable and horticulture	53466	206	412	824
England	15	Built up areas and gardens	12566	48	97	194
England Total				503	1007	2015
Northern Ireland	5	Bog	399	10	20	40
Northern Ireland	6	Dwarf shrub heath	573	10	20	40
Northern Ireland	9	Coniferous woodland	550	10	20	40
Northern Ireland	10	Improved grassland	9507	37	73	146
Northern Ireland	11	Semi-natural grass	1730	10	20	40
Northern Ireland	15	Built up areas and gardens	376	10	20	40
NITotal				87	173	346
Scotland	5	Bog	3757	15	29	58
Scotland	6	Dwarf shrub heath	23151	89	178	357
Scotland	7	Montane habitats	4366	17	34	67
Scotland	8	Broad-leaved / mixed woodland	954	10	20	40
Scotland	9	Coniferous woodland	9722	37	75	150
Scotland	10	Improved grassland	13271	51	102	204
Scotland	11	Semi-natural grass	12165	47	94	187
Scotland	14	Arable and horticulture	7590	29	58	117
Scotland	15	Built up areas and gardens	1375	10	20	40
Scotland Total				305	610	1220
Wales	6	Dwarf shrub heath	711	10	20	40
Wales	8	Broad-leaved / mixed woodland	525	10	20	40
Wales	9	Coniferous woodland	1433	10	20	40
Wales	10	Improved grassland	11033	43	85	170
Wales	11	Semi-natural grass	5785	22	45	89
Wales	15	Built up areas and gardens	655	10	20	40
Wales Total				105	210	419

Note: Count refers to number of 1 km grid squares classified as that land class. S1, S2 and S3 are the number of sample points allocated to the class (the same for all design options) at the three different sampling intensities considered — a total of 1000, 2000 and 4000 points across the UK respectively.

The approach used for illustrative purposes, for all four schemes, was to allocate the sampling points in proportion to the area of each land class in each country with a minimum number of points imposed per land class in each country so as to ensure that it was possible to report on land classes separately. However, before a definitive scheme is determined the division of sampling effort between countries and between land classes needs to be decided on the basis of the specific reporting requirements of each country.

If it is assumed that the variances of the indicators are the same in each land class, allocation in proportion to area is optimal for estimating overall means across land classes, whereas the allocation of an equal number of points to each class is optimal for reporting on individual classes. Whilst it is unrealistic to assume that the within-land class variances are equal, and optimal allocation should therefore also mean that a greater number of samples should be allocated to the more variable land classes (strata), this potential gain in efficiency is problematic to achieve in practice because the variances are different for different indicators.

Technical details of the approaches to obtain sample design options

***Model-based*, s*ystematic (grid) sampling*:** The majority of the sampling locations were on a square grid. The spacing between points on this grid was *x* km where *x* is the smallest integer such that the number of sampled locations is less than 90 per cent of the total number of observations specified in Table 3.3. Two percent of the total sampling locations were positioned 2 km from randomly selected sampling locations on the grid. These observations aided the fitting of spatial models of variation in soil variables by providing information about the spatial variation over short distances. Sampling locations of any Land Cover class that was over-sampled (according to the number of observations allocated using relative areas specified in Table 3.3) were removed at random. The remaining sampling locations were selected to ensure that each Land Cover class was sampled at the specified rate. Initially locations of the required Land Cover class at the centre of the original grid cells were selected but where this was not possible locations were selected at random.

The S2 systematic sample scheme for Wales is shown in Figure 3.1. Most points are spread evenly but there is some clustering due to (i) the inclusion of some close pairs to learn about variation over short distances and (ii) the local extent of some land cover types meaning that the sample scheme must be clustered to sample them adequately.

Model-based, optimised sampling: If the mathematical model of spatial variation is known, then for a particular sampling scheme it is possible to calculate the estimation variances of the means for each variable due to both the spatial variation of the property, and the uncertainty of the model that we will subsequently compute. These estimation variances differ according to the sampling locations. The challenge is to find the distribution of sample points that will minimise the expected value of the estimation variance.

We used an optimisation algorithm known as spatial simulated annealing to find the set of sampling locations that minimised the mean value of each of the estimation variances, within the constraints listed in Table 3.3. This algorithm has been widely used for such problems (for example, see Marchant and Lark, 2006) and we do not consider its detail here. We included a constraint in the optimisation procedure to ensure that coastal sites were not over-represented.

In a real survey the model of spatial variation would be unknown prior to sampling and would be different for each property. In this study we based our sampling scheme on a simple model of the variability of SOC at UK scale. In the assessment of the scheme (below) we generated data from a rather more realistic model. This builds a constraint into the sampling scheme, but it is one that reflects the real-world situation. Because of this we do not automatically expect the optimised scheme to outperform the simpler systematic grid. The simpler scheme could turn out to be more representative.

Figure 3.1 includes the optimised sample scheme for the S2 survey in Wales. It includes a number of close pairs of points. Each pair is generally of a different land cover type so that the differences in means over different land cover types may be accurately estimated.

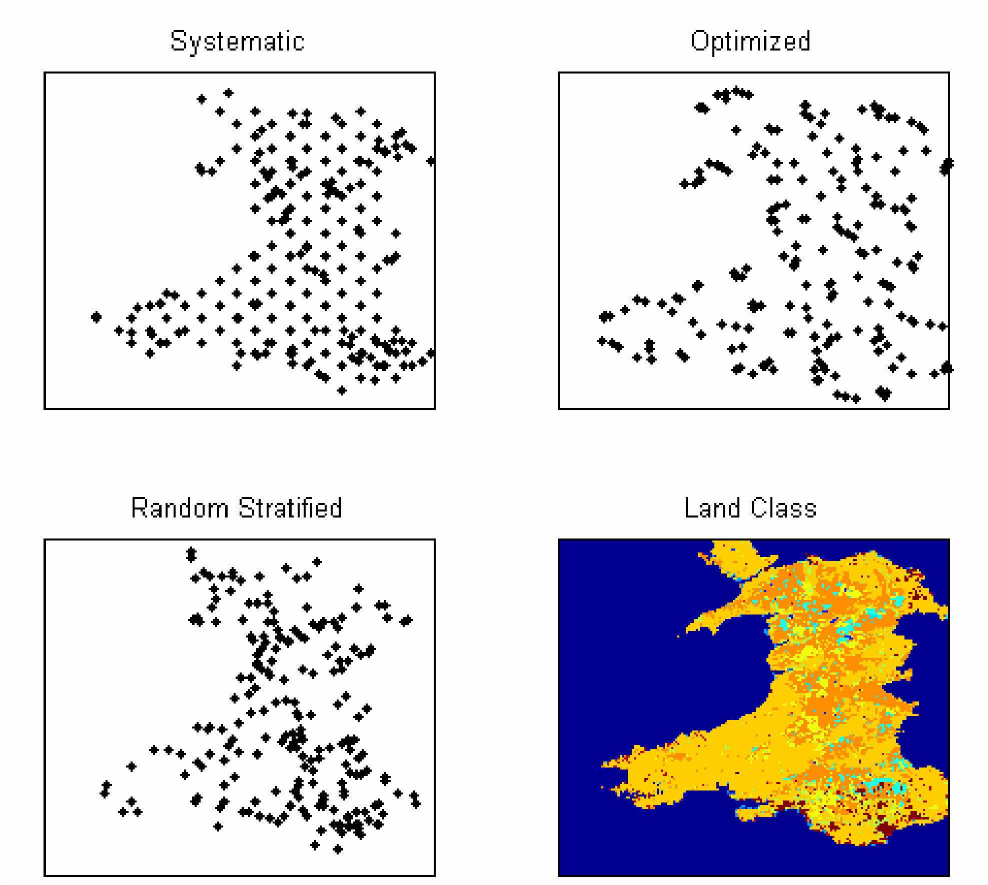


Figure 3.1 Sample designs for Wales at intensity S2 and Land Cover Class map. Wales was used to illustrate the designs since the sample points can be distinguished at this scale.

Design-based, stratified random sampling:

Random sampling can be used to give an unbiased, design-based, estimate of the mean provided the probability of including each unit (such as 1 km square) in the sample is known (and none of these are zero). Just as the design-based estimate of the mean depends on the probability of including each unit in the sample, so the design-based estimate of the variance depends on the probabilities of pairs of units appearing in the sample. Hence an estimate of the variance of this estimated mean can also be obtained provided the inclusion probabilities of all pairs are known, with the proviso again that none of these are zero. The variance of the mean can be greatly reduced if, instead of sampling from the whole population at random, samples are drawn from sub-populations, established by stratification of the sampling locations. Estimates of means and variances can be obtained straightforwardly for each stratum and for any combination of strata. The practical implication of this is that the classification of the UK to draw the sample (the design strata) could be subsets of the classification of the UK for which summary information is required (the reporting classes).

Stratified random sampling is greatly simplified if the assignment of variables to strata is known at the time the sample is drawn, although this is not essential. The broad condition under which stratified random sampling leads to more precise estimates of the mean than simple random sampling is that the average variance between variables that are in different strata must be greater than the average of the variances between variables within the same stratum. Provided this broad condition holds, there is no need to assume equality of the variances between variables within the same stratum.

Assumptions about the distribution of observations are required to construct confidence intervals about estimates of the mean for a variable such as an indicator.

The principal basis we used for defining strata was the Land Cover class and country. However, as we might expect additional variation between widely separated locations within a single Land Cover class, the 1 km squares in England and Scotland were split into seven and four geographically defined blocks respectively (Figure 3.2). Wales and Northern Ireland were retained as single blocks, giving a total of 13 blocks. The proposed sample size for each Land Cover class for each country was divided in proportion to the area of that Land Cover class in each block. The combinations of Land Cover class and geographical blocks formed the stratification from which samples were drawn at random. For some Land Cover classes, blocks had to be combined to form larger strata to ensure a sample size of at least two in every stratum. The resulting stratified random sampling can thus be used to provide estimates for the reporting classes, which in this instance were individual land uses (defined by Land Cover classes as a surrogate for NLUD) in each country.

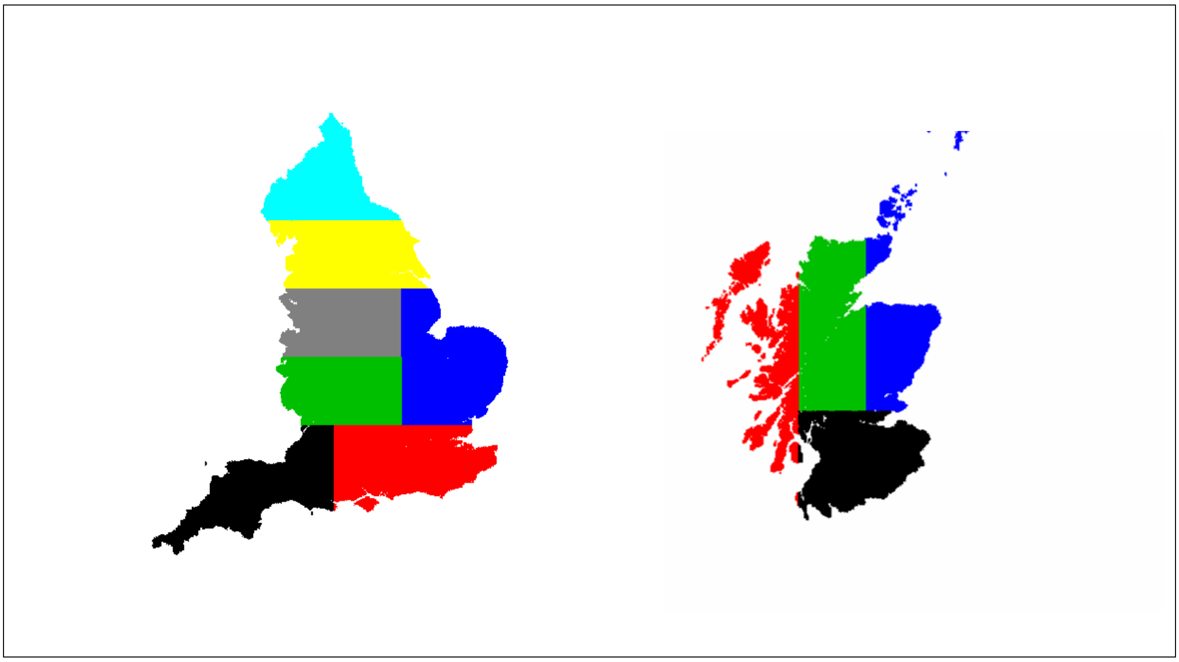


Figure 3.2 Locations of geographic blocks within countries used to increase the efficiency of the design-based sampling schemes.

Design-based, cluster sampling: The costs associated with implementing a sampling scheme will be reduced if less time could be spent travelling between sample locations. Hence costs will be less if the samples are clustered. Conversely, the information in the data may be less than for a random sample using the same number of sampling points because observations within a cluster will be spatially (positively) correlated. We investigated the properties of cluster sampling for samples of size 4000 based on a two-stage process: firstly, a sample of 1000 1 km squares was selected by an identical method to achieve a stratified random sample of size 1000. Four points were then located at random within each of the chosen 1 km squares.

Simulation of values to test sampling options

We use statistical models of the UKSIC indicators to simulate values on which the sampling options can be tested. These models were computed from data available to the project. In the following paragraphs we explain how this was done.

Essentially the model consisted of two components. The first are what are called fixed effects, in this case mean values of the indicators in the different cover classes. The second are random effects, variations about that mean. The random effects have a spatial structure. We therefore modelled them with two elements, first, a distinct value of the variance of the random effect in each class, second an autocorrelation function that describes how the degree of similarity between two measurements of the soil property depends on the distance in space between them.

Available data. Spatial models of the variation of each of the soil indicators were estimated from the following data sources:

- The Countryside Survey (CS) over England, Wales and Scotland
- The National Soil Inventory for England and Wales ($\text{NSI}^{\text{E\&W}}$).
- The National Soil Inventory for Scotland (NSIS).
- The National Soil Inventory for Northern Ireland (NSINI).

The available observations of each soil indicator from each of the above surveys are detailed in Appendix C. For each indicator, the ideal would be to fit different models of variation over each country. These would include different mean values of the indicators over each land cover class. However, there were insufficient observations to fit models of some soil indicators over some land cover classes in some countries. None of the surveys contained measurements of potentially mineralisable nitrogen and therefore this indicator was not considered in this task. Bulk density was only measured in Northern Ireland, so the same model of variation was assumed for each of the countries.

Only a relatively small number of observations were made in Wales, and therefore for each indicator a single model was fitted to the observations from England and Wales. In general where there were insufficient data to decide upon the mean of an indicator over a particular land cover class, the average of the mean values across the other land classes in that country was used.

Where possible it is advantageous to combine the CS data with the NSI and NSIS data since the CS contains a significant number of observations that are separated by a small distance and therefore provides information about the variability of each variable over small scales. In contrast the NSI and NSIS data sets contain more observations and have better spatial coverage and are therefore more informative about mid- to long-scale variation. Differences in the sampling protocols of the surveys mean that the data are not directly comparable and some scaling is required.

Deriving models of spatial variation for individual indicators to estimate mean values for land cover classes

Indicators other than soil organic carbon. For the indicators other than carbon we assume that:

- The indicator has a normal distribution or a log-normal distribution.
- The mean value of the indicator varies according to land class.
- The spatial covariance may be represented by an exponential model

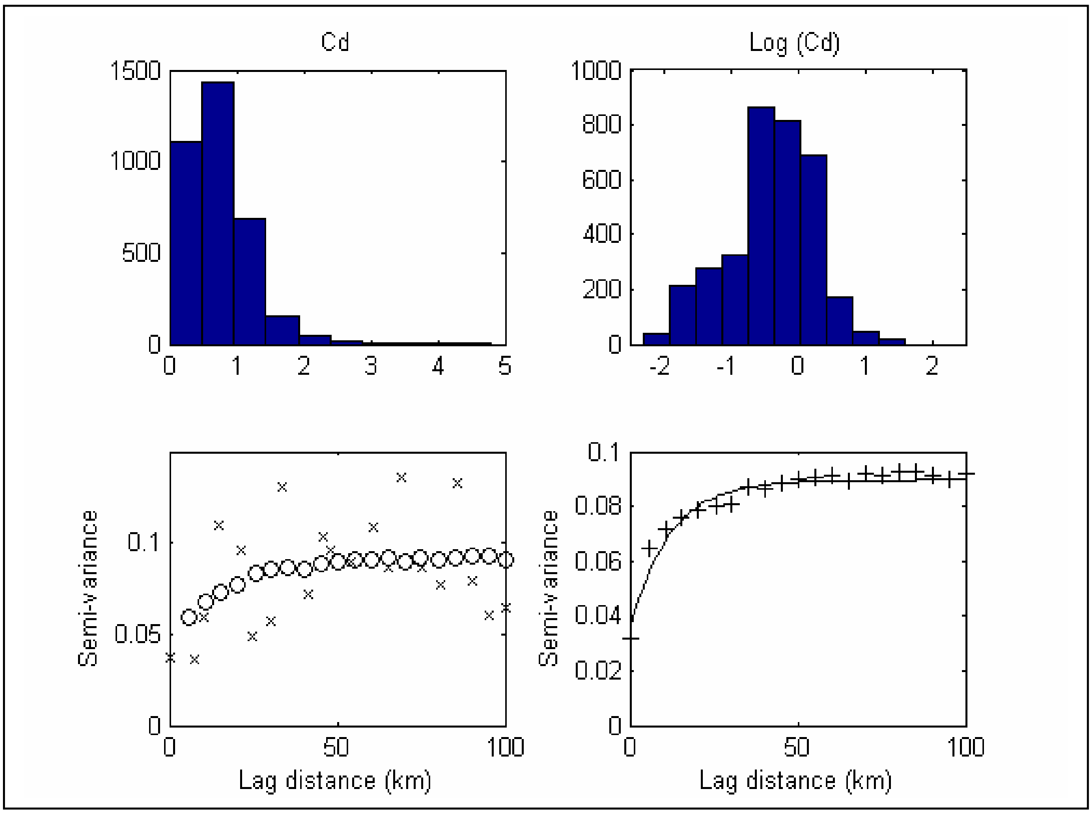
To fit such a model to the available data:

- If both CS and NSI or NSIS data are available, add a constant to the CS data such that both data sets have the same median.

- Decide whether a log transform is required for the assumption of normality to be valid. A log transform is made if the skew of the indicator is larger than one.
- Make a first approximation to the mean value of the indicator over each Land Cover class by simple averaging.
- Subtract the appropriate mean from each indicator value and calculate a point estimate of the variogram for each data set by the method of moments.
- If both data sets are available then scale the CS data such that the average of the point estimates over the five largest lag distances are the same for each data set. Then combine datasets and calculate a single point estimate of the variogram. Note when making these point estimates pair comparisons between observations from different datasets are not included.
- Fit an exponential variogram to the point estimate by weighted least squares.
- Use this estimated variogram to re-estimate the mean over each Land Cover class by generalised least squares.

We are aware that the estimation of variograms by method of moments from ordinary least squares residuals is not unbiased. However, alternative (likelihood) methods would be computationally prohibitive on these large data sets. Another consequence of the size of the data sets is that any bias should be small.

In Figure 3.3 we illustrate this process for soil cadmium over England and Wales. The distribution of cadmium observations from the $\mathrm{NSI}^{E\&W}$ is positively skewed (skew=2.18). Therefore a log transform was applied and the skew reduced to -0.47 and the long tail in the histogram removed. The point estimates from the NSI data (O's in Figure 3.3) were smooth but there were no estimates for lag distances less than 5 km. The point estimates from the CS data (Xs in Figure 3.3) are noisier but provide information from lag distances of <1 km. Point estimates over the shortest lags are known, in general, to be more accurate than point estimates over longer lags. The CS data was transformed as described above to ensure that its median and sill variance matched the $\mathrm{NSI}^{E\&W}$ data. A point estimate of the variogram was then made for the combined data sets (+'s in Figure 3.3) and an exponential model (continuous line in Figure 3.3) fitted to this point estimate by weighted least squares.



Note: The two graphs at the top are histograms showing the frequency of observations in intervals of (left) Cadmium concentration and (right) log of Cadmium concentration. The lower graphs are variograms showing how the semi-variance depends on lag distance (lag distance: distance class interval. Semi-variance: a measure of variability between data points at each distance (lag)).

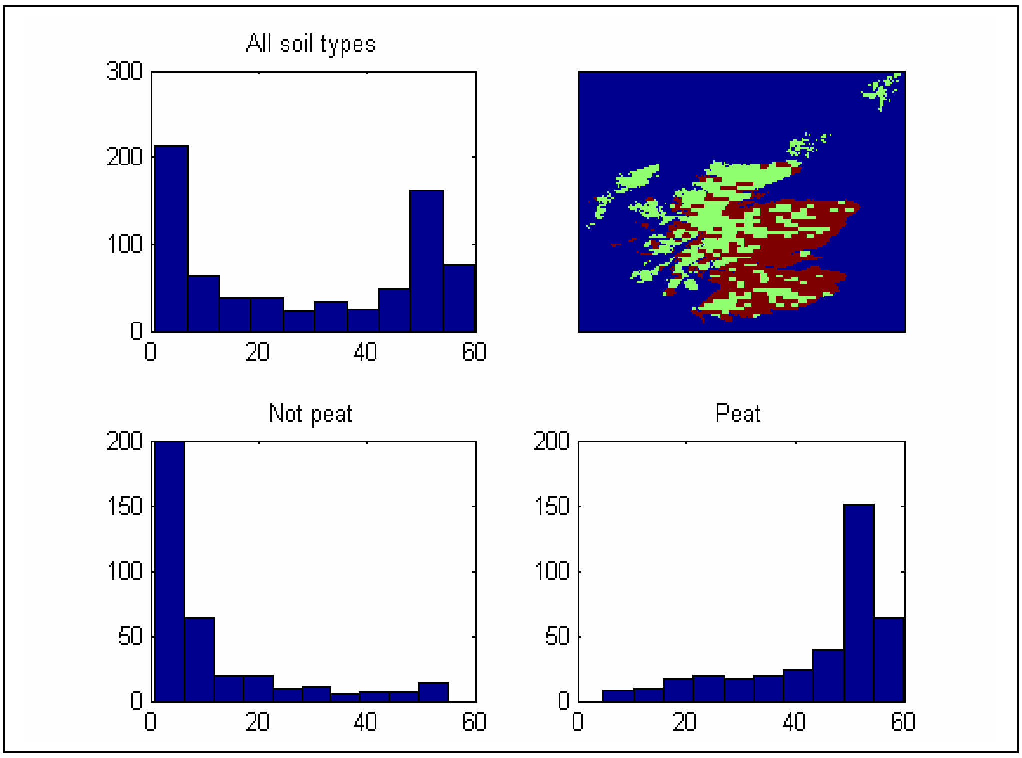
Figure 3.3 Fitting a spatial model for soil cadmium concentration (mg kg^{-1}) over England and Wales.

The variogram is one way of representing the spatial variance model. It shows how the variance of the difference between two observations of the soil (coordinate on the Y-axis of the graph) depends on the distance between them (the lag distance on the X-axis of the graph). The variogram typically approaches a 'sill' value at some lag distance, and at this and longer distances two observations are uncorrelated with each other. The resultant graph indicates that model-based estimation should only be applied if the sampling points are located within 50 km of each other; beyond this there is no spatial correlation between observations to exploit in estimating land-cover class means.

Soil organic carbon. We made a number of changes to the above method when modelling the spatial variation of SOC. A more complicated model of spatial variation was assumed for the status and change in SOC than for the status of the other indicators. This was due to the greater importance attached to monitoring soil organic carbon and it having more complicated spatial variation than the other indicators. For reference, the technical detail was that rather than assuming that the spatial covariance model of the random component of variation is the same over each land class (as previous), we assumed that the spatial correlation of the random component of variation is the same over each Land Cover class but that the variance of the random component varies according to land class.

Distribution of SOC is often bimodal (has two most frequently observed values). Figure 3.4 shows the histogram of SOC in Scotland from NSIS with peaks at around 5 per cent for mineral soils and around 50 per cent, the later due to highly organic/peaty soils. Therefore we used soil maps to divide the UK into areas of peaty and non-peaty soils and fitted separate models for each area. The peaty areas (shaded green in the map in Figure 3.4) cover most of the North West of Scotland. The separate histograms of peaty and non-peaty observations of SOC are not bimodal (lower two graphs Figure 3.4).

Due to the extra complexities in this model no attempt is made to include the CS data and the model was fitted by restricted maximum likelihood methods (REML). Change in SOC was estimated purely from the NSI data and the same approach as for SOC was applied.



Note: The distinction between peat and non-peat was based on the soil classification for the site, not on the measured SOC, which is why the ranges overlap substantially.

Figure 3.4 The distribution of SOC (%) over peaty (highly organic) and non-peaty soils in Scotland.

Simulation of soil variables to obtain realisation means for each design

In order to generate simulated values of soil variables we have to generate realistic values of the random component of variation for each indicator. We simulated these values at the sample sites for each sample scheme using a method called Cholesky factorisation using the fitted exponential model. The fitted mean for the appropriate Land Cover class was then added to each observation, and if appropriate, the log-transform was reversed. This yielded a simulated realisation of the soil indicator with the same pattern of spatial variation as that recorded in available surveys. For the model-based methods we simulated 100 realisations of each indicator over the single example of each sample design, whereas for the design-based methods a single realisation is generated upon each of the 100 designed sample schemes.

Assessing the quality of each design with estimation of sampling variances

The modelling process generated 100 sets of data from a realistic model of the variability of the soil indicators for sampling sites generated under our four sampling options. The next step was to generate from these data realistic measures of the uncertainty of the resulting estimates of the mean values in the Land Cover classes. The quality measure for the sampling schemes was the estimation variance of the realised means. In the remaining paragraphs of this section we describe in more detail how this was done.

Details of the model-based method. The estimation variance for the model-based methods has two components. The first is due to the model used, which has been estimated from data and so is uncertain. The second component is due to the spatial variability that the model describes. The first component of error is often ignored, but should be accounted for if making fair comparisons between model and design-based methods. Both sources of uncertainty were accounted for in computing estimation variances for the model-based methods. Details of how these sources of error were accounted for are discussed below.

The model-based methods were tested by computing the estimation variance for the means from each Land Cover class, with an additional term that accounts for uncertainty about the model parameters. This uncertainty is due to mis-specifying the variogram model or mis-specifying the parameters of the model. Upon simulating indicators, it is assumed that an exponential model could represent the spatial variation of each of our indicators. The more general Matérn model was fitted to the simulated realisations. The exponential model is an example of a Matérn model but the set of Matérn functions is much wider and therefore the effects of model mis-specification may be seen (Marchant & Lark, 2007).

A theoretical expression exists for the uncertainty due to mis-specifying model parameters if the distribution of the indicator is normal or log-normal. Therefore, this expression was used for all of the indicators, except SOC and change in SOC. The outputs of this analysis were an expected mean-square error of the realisation mean and a variance of this mean-square error which shows how mis-specification varies between different realisations of the survey.

This approach to uncertainty in the estimation variance due to model uncertainty cannot be applied for the bimodal carbon distribution. Therefore a spatial model was fitted to each realisation of both soil organic carbon and change in SOC. These were then used to calculate estimation variances. The mean and variance of the estimation variance were recorded. A simple simulation model was fitted to generate the data since it would be unreasonable to assume that the correct form of spatial model was known. This model assumes a different mean over each land cover class and a common variogram model for the residuals from this mean across different land cover classes.

Details of the design-based method. The design-based methods were assessed by computing standard errors from the values realised at the sample points. Since 1 km squares were drawn at random within strata, assessment of the design-based methods began by computing the means and variances of simulated sampled values within each stratum. Estimated means and variances across strata were calculated by weighting the estimates for each stratum according to the proportion of the total that was in that stratum. For the clustered sampling scheme, the mean of the four points in each cluster was calculated first. The resulting values were then used to form means and variances, both for each stratum and for combinations of strata, in the same way as for the stratified random sampling scheme. No assumption of homogeneity of variances between strata is required by any of these calculations. The estimated variances of the means across strata were used to assess these sampling schemes.

Calculation of travelling distances

For each designed sample scheme, a travelling salesman algorithm was used to estimate the distance that must be travelled to visit each proposed sampling location. The algorithm uses simulated annealing to find the shortest route between all points, and it is the length of this route that was then reported. This information was used to calculate travelling costs in Section 4. Note that the route around the points represents a single journey (that is, we assume that breaks in sampling are taken at local centres and do not involve travelling substantial distances back to another centre). More complex assumptions could be made, but not without somewhat arbitrary decisions (for example, on where the sampling team is assumed to be based between periods of active fieldwork).

3.5.4 Results of scheme testing

Indicator estimate reliability

The mean estimation variances for all indicators by land cover class and country are in Appendix D. We present the mean estimation variances over all 100 realisations (and their variances); the mean estimation variance is of greatest interest here. Where the estimation variances are lowest indicates which sampling intensity and/or design option will give the most reliable estimates of an indicator.

Some exemplar results are presented graphically below (Figures 3.5 to 3.11). These show the expected estimation variances for land cover means (within country) at different overall sampling effort by different designs. As expected, as the sampling effort increases so these estimation variances diminish. However, there are (often substantial) differences between the sampling options. These results were selected for illustrative purposes and are restricted to organic carbon and change in organic carbon on three Land Cover classes. We found large differences between indicators and Land Cover classes with respect to the relative performance of the design options, so no manageable selection of graphs could be presented as representative overall.

Logistical considerations

Distance travelled to complete the sampling schemes is shown for all sampling intensities in each country at the bottom of each block of results in Appendix D. These are minimum distances to visit all the sample points, as computed with a travelling salesman algorithm. As noted in section 3.5.3, the route around the points represents a single journey. More complex assumptions could be made, but not without somewhat arbitrary decisions.

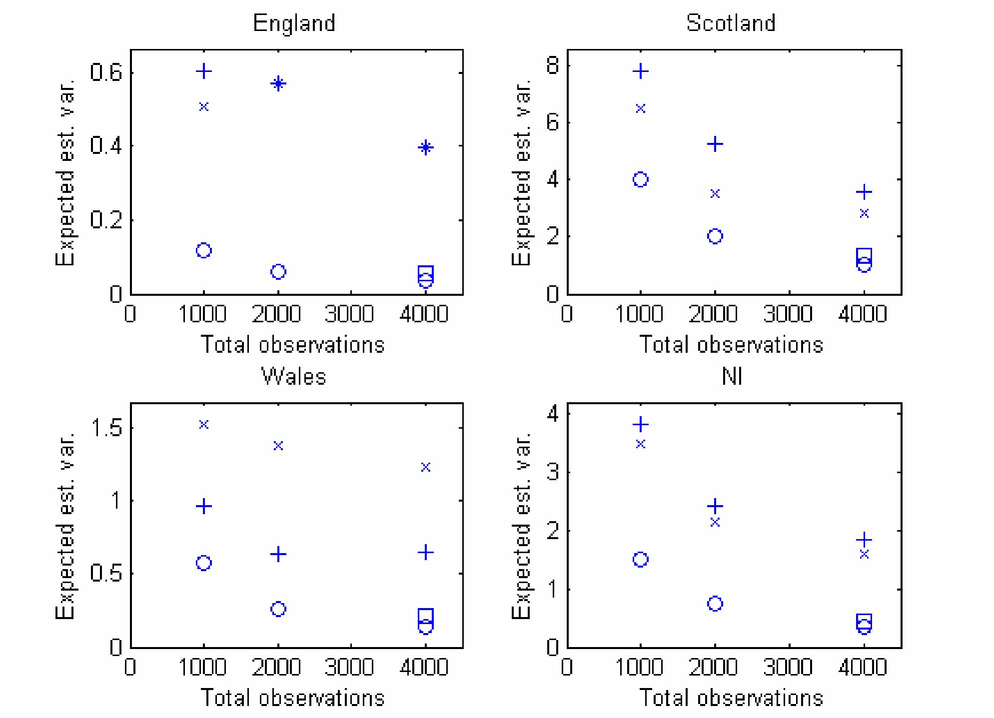


Figure 3.5 Estimation variance for soil organic carbon (g kg^{-1}) in improved grassland

Notes: (o = design-based stratified random sampling; □ = design-based clustered random sampling; + = model-based optimised sampling; x = model-based grid sampling).

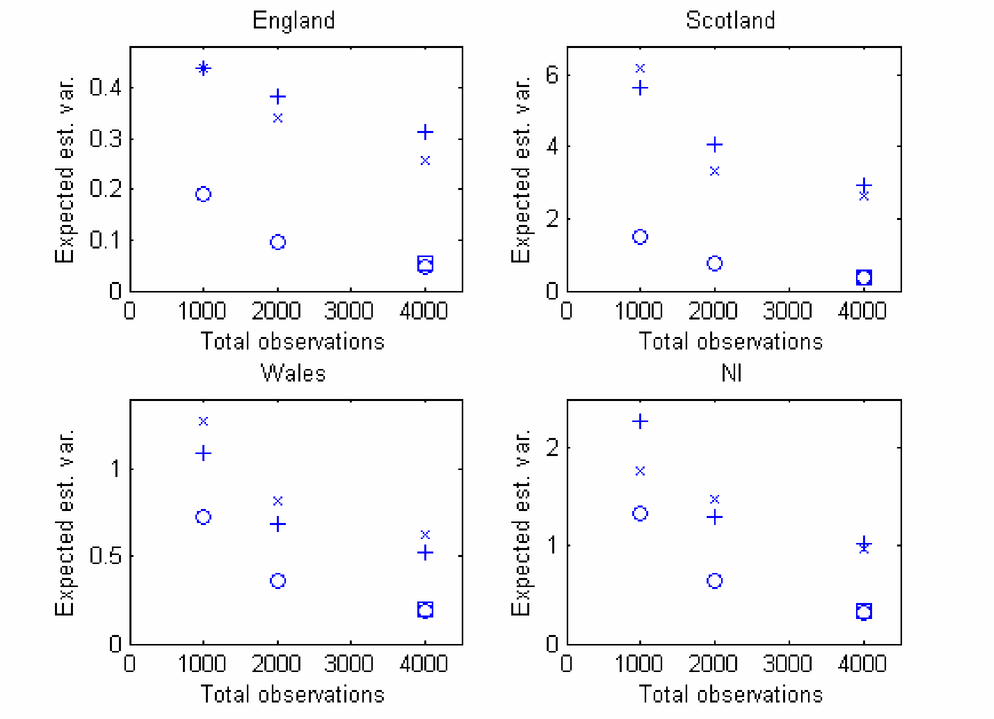


Figure 3.6 Estimation variance for absolute change in soil organic carbon (g kg^{-1}) in improved grassland

Notes: (o = design-based stratified random sampling; □ = design-based clustered random sampling; + = model-based optimised sampling; x = model-based grid sampling).

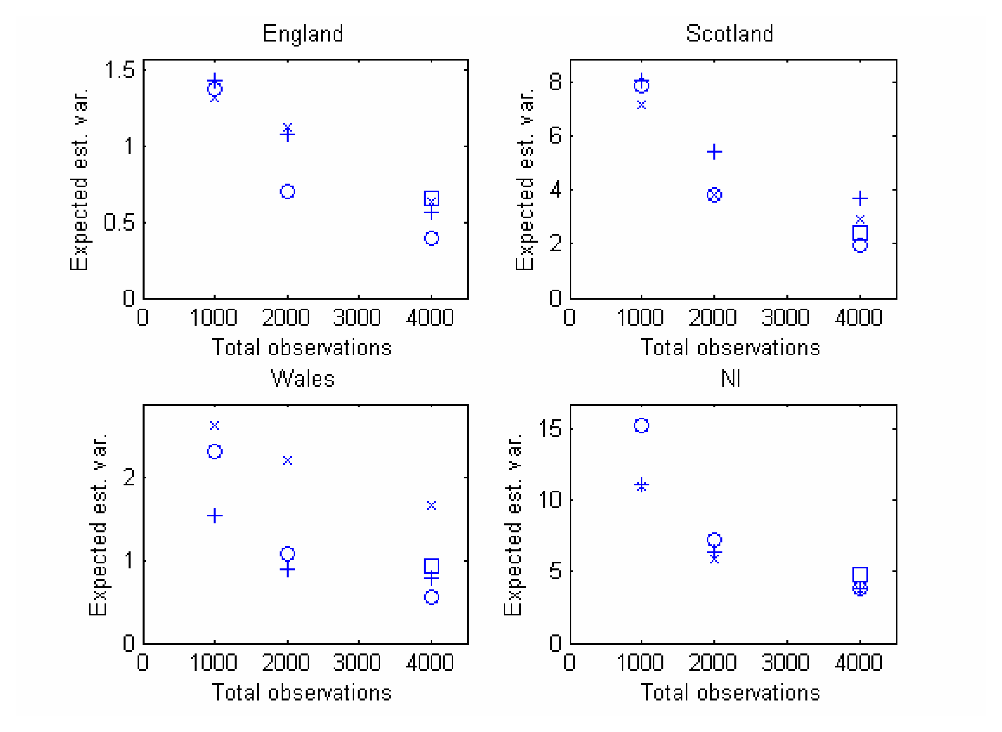


Figure 3.7 Estimation variance for soil organic carbon in semi-natural grassland

Notes: (o = design-based stratified random sampling; □ = design-based clustered random sampling; + = model-based optimised sampling; x = model-based grid sampling).

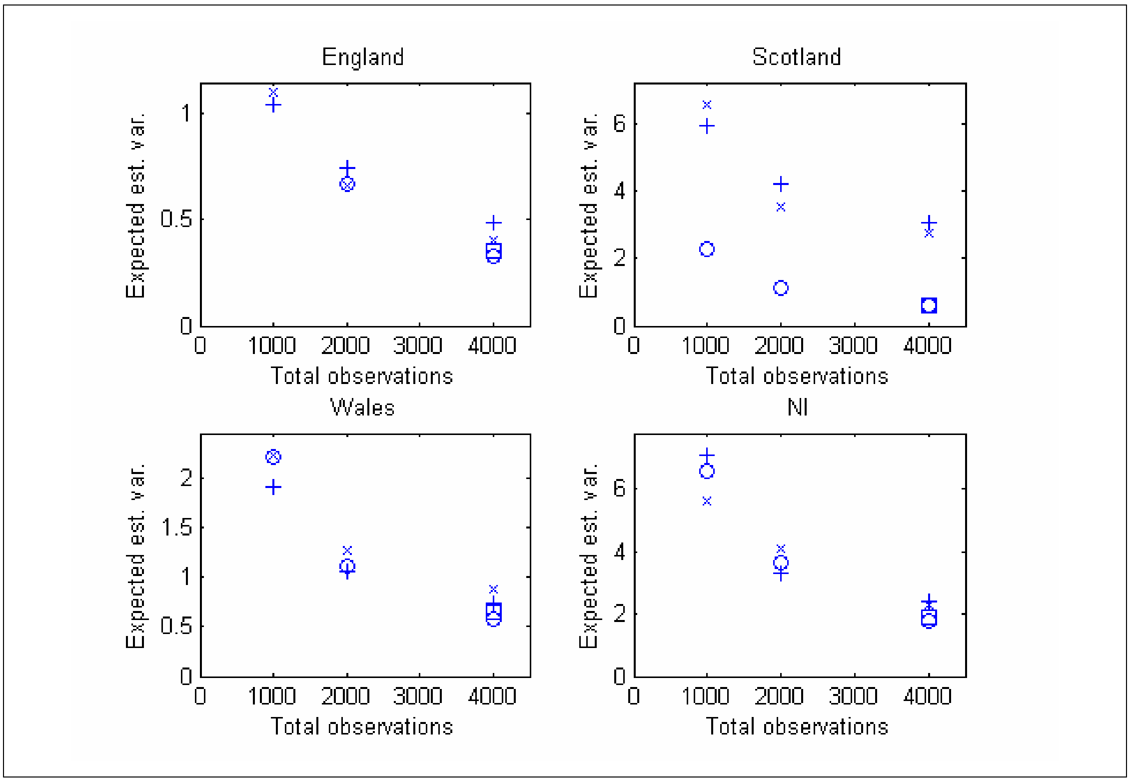


Figure 3.8 Estimation variance for absolute change soil organic carbon (g kg^{-1}) in semi-natural grassland

Notes: (o = design-based stratified random sampling; □ = design-based clustered random sampling; + = model-based optimised sampling; x = model-based grid sampling).

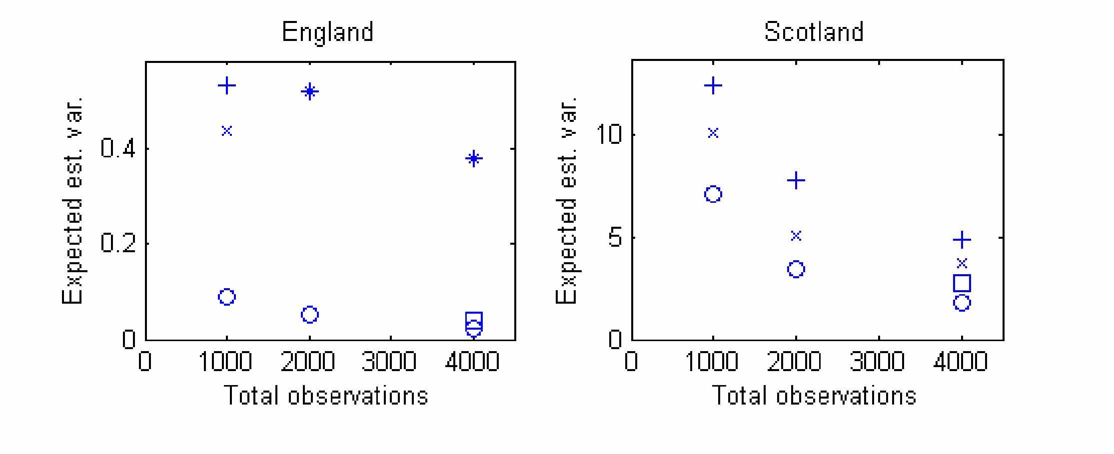


Figure 3.9 Estimation variance for soil organic carbon (g kg^{-1}) in arable and horticulture

Notes: (o = design-based stratified random sampling; □ = design-based clustered random sampling; + = model-based optimised sampling; x = model-based grid sampling).

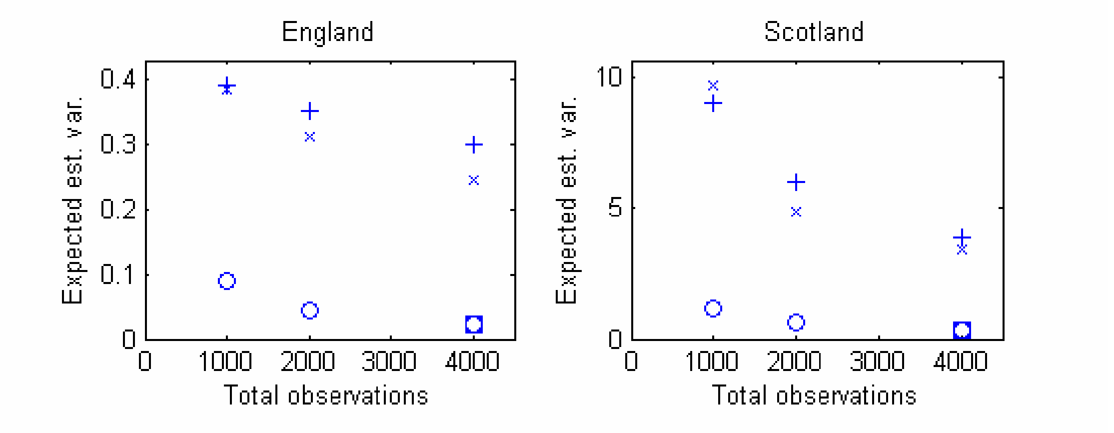
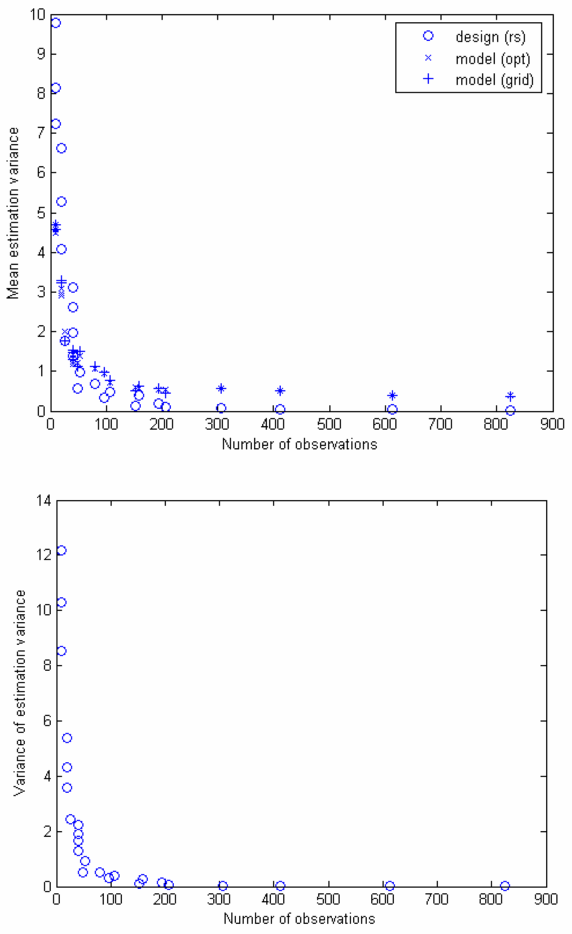


Figure 3.10 Estimation variance for absolute change soil organic carbon (mg kg^{-1}) in arable and horticulture

Notes: (o = design-based stratified random sampling; □ = design-based clustered random sampling; + = model-based optimised sampling; x = model-based grid sampling).



Notes: Top = Mean estimation variance for soil organic carbon over different land cover classes in England against sample size. Bottom = Variance of estimation variances for soil organic carbon over different land cover classes in England against sample size.

Figure 3.11 Estimation variance for SOC over different land cover classes in England against sample size

3.6 Discussion of designing options

A detailed synopsis is presented in the following section of this report, with consideration of the quality measures required for the actions levels of each indicator.

3.6.1 Scheme performance for target indicators

For SOC status, change in SOC and several other canary indicators, design-based sampling performs better than model-based sampling as measured by the estimation variances. In some cases (particularly change in SOC) these differences are substantial. Similar results have been obtained for change in SOC from previous simulation studies (for example, Saby and Arrouays, 2004; Peltoniemi *et al*., 2007). This observation can be attributed to two factors:

- Model-based estimation has the greatest advantage over design-based alternatives when the target variable shows strong spatial autocorrelation (when samples taken from sites nearer to each other are more similar than those taken from sites further apart) as this is modelled and accounted for in the estimation. In the case, for example, of change in SOC in England, the spatial auto-correlation is weak. Of the total variance only 6 per cent (non-peaty soils) or 2 percent (peaty soils) is spatially correlated, and the effective range of spatial dependence is 180 km (peaty soils) and 300 km (non-peaty soils). In contrast, the spatial correlation of bulk density (derived from data in Northern Ireland) is strong, and indeed the model-based schemes gave better results than design-based schemes. In this case, 78 per cent of the variance is spatially correlated, and the effective range of spatial dependence is about 50 km.

- In the model-based case we have to use our data to estimate parameters of the spatial model, and the uncertainty in this model is accounted for in our computed estimation variances. In these trials we simulated SOC and change in SOC with a complex model to describe the available data (separate distributions and spatial parameters for peaty and non-peaty soils). The fitted model was simpler (to emulate our less-perfect knowledge of the true model in reality), and because the data are simulated from a bimodal process, the fitted models are likely to overestimate the variance. Since we are fitting a relatively simple model to data drawn from a more complex one, the contribution of model uncertainty to our estimation variances will be significant.

In summary, the differences between our results for model-based and design-based methods in part reflect the spatial dependence of the target variables, but also the uncertainty from the different mathematical approaches to characterising variability of indicators. It would not be reasonable to ignore this uncertainty in this assessment, but this had to be carried out without favouring model-based approaches unduly by using a model for estimation that was very close to the one that had been used for simulating data. This means that it is difficult, in the context of this study, to make an entirely fair comparison between model- and design-based approaches and, in the case of the SOC and change in SOC, the model-based approaches may well have been unduly penalised. However, the weight of results across the different indicators remains in favour of design-based methods and can be considered reasonable given that the goal is to estimate global means (for different land cover classes). For SOC status and change in SOC, estimation variances are generally smallest for the design-based method with stratified random sampling. A clustered random stratified scheme provides a reduced amount of travelling although estimation variances are slightly raised. (Figures 3.5-3.10). For other indicators, design-based methods also generally showed lower estimation variances than model-based.

3.6.2 Scheme performance for reporting by land use

To examine reporting by land use, both model-based and design-based methods used information about Land Cover class in the selection of the sampling points and in the analysis of the simulated data. The target estimates presented in this report are global means (mean values for Land Cover classes across each country), rather than local estimates. Our results, which generally favour design-based approaches, are supported by previous comparable research showing that design-based approaches are the most suited to global estimation problems (De Gruitjer *et al.*, 2006; Papritz and Webster, 1996).

The Land Cover approach used for illustrative purposes was to allocate the sampling points in proportion to the area of each land class in each country, but with a minimum number of points imposed per land class in each country so as to ensure that it was possible to report on land classes separately. However, before a definitive scheme is determined the division of sampling effort between countries and between land classes needs to be decided. If it is assumed that the variances of the indicators are the same in each land class, allocation in proportion to area is optimal for estimating overall means across land classes, whereas the allocation of an equal number of points to each class is optimal for reporting on individual classes. It is unrealistic to assume that the within-land class variances are equal, and therefore optimal allocation would involve a greater number of samples allocated to the more variable land classes. However, this potential gain in efficiency is problematic in practice because the variances are different for different indicators.

The following allocations of sampling effort are therefore recommended for different purposes:

- For reporting UK means or totals – allocation in proportion to the area of each land class in each country.
- For reporting means or totals at devolved administration level – an equal number of samples in each country allocated to land classes within countries in proportion to area.
- For reporting means or totals within land classes within countries – an equal number of samples allocated to each land class in each country.

As the allocation that is optimal for one purpose is sub-optimal for others, it is important that they be prioritised.

3.6.3 Influence of stratification classes on scheme performance

There are many options for stratification across both the UK and at the individual country-level. Other categorical variables could be used during the design phase to stratify, the principal constraints being: a) that they should be available at the time of drawing the sample for the whole area to be sampled; b) variation between measured variables within strata should be as small as possible; c) they should ideally either be the reporting categories, or be sub-divisions of the reporting categories.

The options selected for this study were based on the availability of spatial information on potential land use and geographical characteristics of individual countries. The use of Land Cover Class was illustrative, but it is unclear what alternative stratification would be a substantial improvement given the above constraints. The regional blocks defined for England and Scotland were introduced to increase efficiency of the design-based methods, and led to sampling strata that can best be thought of as regional blocks within land cover classes. This procedure could easily be modified to allow for sources of variation other than geographical location, that are important for many of the variables to be measured.

Land Cover classes are compatible with the requirement to report indicators by land use according to the NLUD classification, since LCM classes and NLUD classes are almost entirely compatible. Although there will be discrepancies between Land Cover and actual land use, errors in Land Cover could be refined prior to establishing sampling locations by relating Land Cover to actual land use from other sources such as aerial images or agricultural census information for each country. Unless dramatic, most land use change between monitoring intervals can be accommodated in the contingency to ensure that adequate sample numbers are maintained to report by land use; for example, for a design with 4000 samples, a 1 per cent change in land use across UK would only change 40 sampling locations.

It is also possible to derive statistically-based environmental stratifications (c.f. Bunce *et al*., 2004 (ITE Land Classification), or Jongman *et al*., 2006, for Europe). Such stratifications are known to be useful for assessing and monitoring biodiversity, land cover and land use but have not been investigated specifically for soil monitoring, as yet.

3.6.4 Performance of schemes for other reporting classes

All of the sample designs placed a lower threshold on the number of observations over each relevant Land Cover class within each country. Similar procedures could be applied to ensure that other reporting units (such as regions with contrasting UKCIP climate change scenarios or contrasting atmospheric deposition rates) were adequately sampled. However, constraining the sample schemes in this manner may mean that the monitoring survey is less efficient at detecting changes due to other factors that are not known at present and may mean that the monitoring scheme is inefficient if the reporting classes of interest change over time. This problem can be addressed to some extent by including additional samples in the design to add flexibility, although this adds cost to the scheme.

3.6.5 Impact of sampling intensity on scheme performance

A set of sample coordinates for each of the sampling options at each of the sampling intensities were generated. However, it is not intended that these are taken as actual sampling sites for a preferred sampling scheme selected by UKSIC for the following reasons:

- Because of the logistical and computational demands of this task, three sampling intensities were selected to test and compare the different design options. Having agreed on a general strategy, these sampling intensities should be adjusted to the exact criteria required from any preferred sampling scheme (for example to 3500 points, or 4250 rather than 4000 exactly).

- The list of Land Cover classes used in each country was determined in part by what data was available. This should not necessarily prevent the inclusion of other classes (land uses), nor indeed the exclusion of some classes to improve estimation in others, if there are clear policy reasons for these choices. These would require revising the sampling intensities and locations accordingly in the preferred sampling option.

- Similarly, UKSIC may consider that some relatively infrequent land uses are important for specific reasons and therefore essential in a Tier 1 network. Further adjustment of sample allocation would be needed to improve the precision with which they could be monitored. By the same token, there could be scope to reduce effort in some of the larger classes. This could be judged using additional data, but will depend on UKSIC priorities. These would require revising the sampling intensities and locations accordingly in the preferred sampling option. It is worth noting that our results suggest that the precision of estimates (design- or model-based) across any reporting unit decreases rapidly when there are fewer than 100 observations within that unit.

- The division of effort between England, Scotland, Wales and Northern Ireland was proportional to land area in the selected classes. Adjustment would be possible if there are variations in requirements between countries, ensuring that local requirements for information on particular classes is met, or if different levels of funding are available in the different administrations.

- Some supplementary sampling could be accommodated for certain indicators, over and above that required for the canary indicators, should this be deemed necessary.

Workshop Box 15: Further discussion of design options

Our findings are in line with other published research, in that estimation of means of large areas from model-based sampling from a grid is generally less efficient than design-based estimation from stratified random sampling. Complete sampling of a regular grid is not suitable for Tier 1 soil monitoring because of the requirement to provide estimates of status and change in soil indicators for a range of land uses within countries (the reporting units). The size and spatial pattern of these reporting units differ greatly and each may only be sampled adequately if the regular grid is distorted as in our study (see, for example, Figure 3.1), or if the grid is incompletely sampled. Our results suggest that the precision of estimates (design- or model-based) across any reporting unit decreases rapidly for less than 100 observations within that reporting unit (Fig 3.11). Therefore even further distortion of the regular grid would be required to achieve adequate sampling of all reporting units.

If a completely new monitoring scheme were to be set up, we would recommend a stratified random sampling scheme in which stratification is used to ensure the best spatial coverage possible and is consistent with adequate sampling of all classes.

The exact sample sizes required would depend on acceptable tolerances for specific reporting requirements and their action levels. Although varying the sampling intensity to achieve adequate sample sizes within all reporting classes achieves the principal design, there are also disadvantages of such schemes. First, it should be noted that if sampling is not in proportion to area, design-based estimation of reporting classes that have not been included in the design (secondary reporting classes, for example soil type) will be more complicated. Second, the number of sampling points lying within a secondary reporting class will depend not just on the area of this class but also on the distribution of this area across the primary reporting classes. If the monitoring scheme is required to allow adequate estimation for secondary reporting classes, more samples will be required than the minimum needed solely to give adequate estimation in the primary reporting classes. By incorporating peaty/non peaty soils types into the design phase, we demonstrated that the inclusion of secondary information can also improve the ultimate sampling design but this will always be dependent on the spatial coverage and quality of pre-existing information.

Similarly, the initial design needs to make some allowance for potential future changes in land classes at sampling locations and for potential future unavailability of the initial sampling locations, although these latter points apply to all possible schemes. We recommend a minimum contingency of 20 per cent, however this should be assessed when the specifications for each country are finalised as individual countries may require greater contingencies if there are significant requirements for secondary reporting or interpretation.

Workshop Box 15 continued

It should be noted that our findings for the systematic sampling schemes were based on full geostatistical estimation. If there were strong ancillary reasons for using a grid sample for a Tier 1 monitoring programme, then one possible improvement would be to treat the observations on the grid as though they were a simple or stratified random sample. This would give a conservative estimate of variance (tending to be too large) under some quite general conditions that are likely to hold for large-scale sampling. This approach parallels the grid component in the original design of Countryside Survey and it could equally be applied to the National Soil Inventories in England & Wales, Scotland, and Northern Ireland. For a systematic sampling scheme such as the one used in our simulation study, in which a fraction of the sampling effort is invested in estimating spatial correlation between pairs of points that are closer together than the grid spacing, another possible approach would be to use a design-based method to estimate the sample means but a model-based method to estimate the variances of the means.

3.7 Conclusions from designing options

The weight of results across the different indicators are in favour of a design-based approach to a UK soil monitoring scheme, particularly if the primary objective is to estimate global means of the target indicators by land use within each country. For most indicators, but especially SOC status and change in SOC, the estimation variances were generally smallest for the design-based method with stratified random sampling, with design-based methods generally showing lower estimation variances than model-based.

It is important for UKSIC to determine the ultimate priority for reporting (for example, land use in country or country-level means) as this will affect the allocation of sampling locations, given that allocation optimal for one purpose will be sub-optimal for others. This in turn will influence the choices for stratification, sampling intensities and ultimately cost.

4 Critical assessment of the design options

4.1 Introduction

Within this section of the report, the detailed information from section 3 is brought together in a decision support matrix, to enable the different sampling schemes to be compared. This includes the relative performance of the design-based and model-based schemes to provide information on both the status and change in all soil indicators for each land use within each country and potential costs for the different sampling schemes for individual countries.

It is clear that a decision on the sampling scheme cannot be made by a simple rule from the statistical results without weighing other considerations as discussed in the following section. There are several indicators to consider with contrasting behaviour, while the proposed soil monitoring scheme is expected to deal with many issues: identifying soils at risk, estimating change by land use, monitoring effects of climate change and so on. Flexibility of the design is therefore important. It is important however not to attempt to "tweak" the design to meet many contrasting criteria (as the contrasting results for different indicators in our results indicate). A summary of the outcomes for each country is provided to aid the decision-making process, based on a UK sampling intensity of 4000 (Table 4.24).

It is important to note that the project was tasked with reporting indicators by land use as the primary requirement and there was no consideration of overall country-level means for either design-based or model-based options. As outlined earlier, this would be a technically challenging task for the model-based approaches. This requirement is reviewed within section 3.6.5, which explores the opportunity to alter the sampling intensities within countries to improve the information gained on individual indicators.

To assess the performance of the different design options, two areas were considered. First, the overall differences in the scheme design and second, how the schemes perform against quality measures including tolerance levels.

4.2 Assessing the relative performance based on the design options

As described previously, the four different sampling schemes are:

Model-based, systematic (grid) sampling (Gr): 1000, 2000, 4000 samples

Model-based, optimised grid sampling (Opt): 1000, 2000, 4000 samples

Design-based, stratified random sampling (RS): 1000, 2000, 4000 samples

Design-based, cluster sampling (RC): 4000 samples

Model-based and design-based schemes have their own advantages and disadvantages, outlined below.

4.2.1 Factors in favour of model-based approaches

Greater flexibility for estimating mean changes according to a new reporting class that is not nested within the one used for the initial design (particularly from the systematic (grid-based) model). For example, if a particular problem became apparent (for example loss of soil carbon from unimproved grassland in Wales), and it was decided to look at this in more detail according to soil type, then the systematic model-based approach will generally be more flexible because most sample points are not allocated according to rules determined by a particular Land Cover classification.

The systematic (grid-based) sampling scheme should be *relatively efficient at detecting effects associated with factors not yet known***.** This is related to the first point above. Systematic sampling is generally more efficient than randomised sampling for detecting new phenomena and therefore has more flexibility for incorporating future (as yet unknown) requirements.

Most efficient approach should maps of status or change (or other information requiring point estimates) be wanted subsequently. Should UKSIC decide at some point in the future that it requires maps at UK or country-scale of status or change (perhaps because some particular problem has emerged where the spatial pattern might be of particular importance, and is not entirely captured by the land cover classification), or point estimates at national scale are needed for other purposes (such as for broad-brush studies using process models), then a systematic sample will provide a better basis for doing this than a randomised sample.

4.2.2 Factors weighing against model-based

Risk of bias due to systematic sampling. There is a risk of bias in systematic sampling should the sample grid coincide with some periodic source of variation. This is not very likely at a UK scale but may be relevant at a regional or country-level.

Risk of bias when interpolating for poorly sampled reporting units. In principle, model-based analysis allows us to interpolate between the sampling points, hence allowing estimates to be obtained for reporting units other than those specified at the time of design. However, such interpolations are based on the assumption that points outside the new reporting unit are consistent with those inside. If, in reality, the mean status (or change) for the new reporting unit is genuinely different from the strata used in the design, and if few observations have been made in the new reporting unit, then such interpolated estimates will be biased and the bias may be large.

Model uncertainty. Our assessment accounts for the uncertainty in the estimates of model parameters obtained from our data. However, this does assume that the general form of the spatial covariance model is correct. This is why a very flexible model was selected (the Matérn function) as this encompasses a wide range of behaviours, particularly in spatial variation over short distances.

Stationarity assumptions. At its simplest, the model-based approach assumes that the form of the spatial correlation is the same everywhere. Note, however, that approaches to relaxing this assumption are the subject of current research. The balance between improved estimation due to relaxing the stationarity assumption and the requisite sample size to allow local estimation of variances and covariances has yet to be assessed.

Lack of flexibility. Having opted for a model-based design we are committed to model-based analysis, even when the spatial structure of the variance turns out not to be clearly expressed, for example spatial correlation of the data is weak (see factors in favour of design-based, point 4).

4.2.3 Factors in favour of design-based

Lack of bias. Design-based sampling always gives unbiased estimates of the mean and variance.

Simplicity. The design-based statistics for stratified random sampling and cluster sampling are straightforward to compute.

Lack of dependence on spatial covariance model assumptions. The mean and variance of design-based estimates require no assumptions about the distribution of observations (such as stationarity in the variances or autocorrelation). This makes the design-based approach transparent and hence robust against criticism.

Flexibility with respect to analysis post-sampling. Both design- and model-based statistical analysis can be used on the data collected in this way. For example, having sampled from a design-based scheme, we can subsequently use model-based analyses in which we exploit any spatial correlation in the variability.

4.2.4 Factors weighing against design-based

Less flexible. The design-based sampling schemes control the number of samples with respect to the design strata. If estimates are required for areas that are not design strata or cannot be formed from combinations of design strata, then such areas may be over- or under-represented in the realised sample. Hence the estimate for the mean of this new stratum may have lower or higher efficiency than would have been achieved if it had been included in the design. Correct design-based statistics could usually be computed: such estimates may require complex formulae, undermining one of the key advantages of the design-based approach, but would still be free of distributional assumptions, retaining another key advantage of the design-based approach. If the new area for estimation is sufficiently small, then the original design might contain inadequate points with which to estimate summary statistics. Estimates for small areas or even points can always be obtained by using model-based methods with data from sites selected by design-based sampling schemes. However, these will, on average, be less efficient than if model-based sampling had been used.

Assumptions. Distributional assumptions (usually normality or log-normality) are required to derive confidence intervals from the estimated variances.

4.3 Assessing the relative performance of the sampling scheme against quality measures

Two approaches were adopted to assess the relative performance of the sampling scheme options. The first evaluated both model-based and design-based options using expected confidence interval width and sample size calculations. The second assessed the relative performance of the design-based schemes based on statistical power calculations and sample size calculations. Model-based were not considered in the second assessment due to immense requirements for computing capacity.

The two examples below illustrate the different quality measures against which the performance of the individual schemes can be assessed.

Example 1. Assessment of a status indicator and comparison with an action level. An action level may specify that action should be taken if, for example, pH is less than 4.5. To assess whether there is evidence that action should be taken, some thought is required over whether the intention is to assess whether action is unlikely to be required (for example, the true mean for pH is greater than 4.5) or whether the intention is to assess whether there is evidence to suggest that action is required (for example, the true mean for pH is less than 4.5). The former represents the 'precautionary approach', the latter stance is one of 'only act if we must'. In either case, the null hypothesis that we need to test is that the true mean is equal to the action level.

If the action level for class A is pH 4.5, we will be able to assess how compatible the data are with the true pH value being 4.5. To do this, we would have to make some assumptions about distributions (that are generally reasonable for sample means) and on the basis of these assumptions estimate a confidence interval for the true mean given the observed data. The coverage probability (say 95 per cent) of the confidence interval is the chance that it contains the true value. The statistical significance level (100 per cent minus the coverage probability of the confidence interval with the action level as an upper or lower limit) is the chance of getting a mean at least as extreme as that observed if the action level were the true mean. Lower significance levels provide stronger evidence against the hypothesis that the action level is the true mean, but we can never be certain. Note also here that inclusion of the action level in the confidence interval is not evidence that the action limit has been exceeded. This describes a post-hoc evaluation of uncertainty (that is, it is for a particular case when we have estimated a mean and variance from gathered data).

In advance, given estimates of the variance of the sample mean, we could estimate the likely widths of confidence intervals derived from given sample sizes. The design problem, then, is to specify what statistical significance level will be used (how likely we are to think an action level has not been reached when in truth it has), and what statistical power is required (how likely we wish to be to obtain a statistically significant result given that the true mean is not the action limit). For example, if the true mean pH for class A is 4.2, we may wish to have an 80 per cent chance that the 95 per cent confidence interval does not contain 4.5 (and hence the results are statistically significant at the 5 per cent level). These sample size calculations are dependant upon agreement with the end-user on the significance level for statistical tests and the power for a stated difference between the truth and the action limit.

Example 2. Assessment of a change indicator and comparison with an action level. Exactly the same issues apply for change indicators, for example, change in pH, with the proviso that we are now working with mean change and variances of change, and treat 0.5 pH units as an 'action limit' for change. Sample size calculations are dependent upon agreement with the end-user on the significance level for statistical tests and the power for a stated difference between the true change and the action level for change, here 0.5 pH units.

4.3.1 Methods for sample size calculation based on expected confidence interval width

If we have an estimate, $\overline{x}$, of a mean, μ, and the sample variance is σ^2, then we can compute a tolerance *d*, the maximum error $|\overline{x} - \mu|$ such that μ is in the 95 per cent confidence interval about $\overline{x}$. In other words, we can calculate the tolerance based on the estimated mean and variance at a specified confidence level. Increasing the sample size will reduce the tolerance. Quality requirements have often been expressed in this form in the checklist. Therefore we can compare the expected tolerances at different sample sizes with the required tolerances to determine the sample size needed for the monitoring scheme to be of acceptable quality.

The relative performance of each scheme was evaluated against tolerance levels. This was completed for the canary indicators using tolerance levels determined by UKSIC, where available, or the project team. Tolerances defined by the project team are for illustrative purposes only. It should be noted that, although the best use was made of available data, the models are not entirely satisfactory. Therefore, the following should be taken as a guide, to aid the final decision-making process only, and should not be treated as fixed.

4.3.2 Results for sample size calculations based on expected confidence interval width

Soil Organic Carbon quality indicator

There are two sets of results for this indicator

- *Soil organic carbon status*. The minimum detectable difference in SOC status at 95 per cent confidence was determined (that is, the smallest difference from a threshold that could be detected with 95 per cent confidence) for each scheme. A requirement was made that the monitoring scheme should show that, for any sampling phase, mean organic carbon (%) could be measured to within five per cent SOC. The results are summarised in Table 4.1. Further details of which land classes meet the criteria are given in Appendix E. For example, in England, the model-based optimised grid sampling gives the required precision across all Land Cover classes for all sampling intensities, so an intensity of 1000 (on a UK basis), might be the preferred option. Scotland is the only country where this level of precision cannot be met for all land cover classes. Here only seven out of nine land cover types can be estimated reliably using the model-based systematic grid based scheme with 4000 points, with six for the stratified random sampling. Overall it seems that the model-based options perform better for this indicator.

  It should be noted that for some classes in England and Wales the mean value of SOC is less than five per cent. With this level of precision, a scheme would not be able to determine whether the SOC levels in these classes were above zero. Different precision levels may need to be defined for each reporting class.

Table 4.1 Number of land cover classes able to estimate mean organic carbon levels within 5%SOC.

	England				Scotland				Wales				Northern Ireland			
Classes / country	8				9				6				6			
Scheme/ sample size	Gr	Opt	RS	RC	Gr	Opt	RS	RC	Gr	Opt	RS	RC	Gr	Opt	RS	RC
1000	8	8	5	-	1	1	2	-	6	6	4	-	1	1	1	-
2000	8	8	7	-	5	4	5	-	6	6	6	-	6	1	2	-
4000	8	8	8	8	7	5	6	5	6	6	6	6	6	6	6	4

Notes: The scheme with the best precision and smallest effort highlighted in red/dark shading. A close second choice is highlighted in blue/light shading.

- *Change in soil organic carbon.* The quality measure for this indicator was the ability to detect a 20 per cent change in the baseline SOC status. A separate value of the acceptable tolerance (d_c) was computed for each land cover class in each country. The results are summarised in the Table 4.2, using the same colour coding as before (further details in Appendix E). Note that the model, based on available data, is for change in SOC over a period of 10–20 years. The schemes for Wales and Northern Ireland do not perform well at detecting change, with the best scheme for Wales (RS) only having two out of the six land classes that meet the criteria, increasing to four out of six for Northern Ireland.

  It should be noted that this is a rather limiting quality measure, and that the error variances are likely to be overestimated (due, for example, to our uncertainty about the true class at sampling points when the model was fitted). To meet the criteria the stratified random sampling would have to be used, with a substantial movement of sample effort from larger land-cover classes to smaller ones (particularly smaller ones where the mean SOC is relatively small), as illustrated by the power analyses below. Alternatively, it would have to be accepted that monitoring at this level of precision has to be done for wider classes than those used here.

Table 4.2 Number of land cover classes within which the sample variance is less than critical variance for SOC change.

	England				Scotland				Wales				Northern Ireland			
Classes / country	8				8				6				6			
Scheme/ sample size	Gr	Opt	RS	RC	Gr	Opt	RS	RC	Gr	Opt	RS	RC	Gr	Opt	RS	RC
1000	0	0	2	-	1	1	6	-	0	0	0	-	0	0	0	-
2000	2	1	5	-	3	3	6	-	0	0	0	-	1	3	2	-
4000	5	3	7	6	4	4	8	8	0	1	2	2	3	3	4	4

Notes: The scheme with the best precision and smallest effort highlighted in red/dark shading. A close second choice is highlighted in blue/light shading. A model for change could not be obtained for "Montane Habitats" in Scotland.

Soil pH

Note that there is no information on change in pH. As an example, however, it has been assumed that mean pH can be estimated with a tolerance (95 per cent confidence) of ±0.5 pH units. The results are summarised in Table 4.3, which shows that all sampling schemes are able to meet the criteria. For Scotland and Northern

Ireland, the overall sampling intensity of S1 (1000 across the UK) is sufficient, while for England and Wales the S2 (2000 across the UK) sample design would be needed.

Table 4.3 Number of land cover classes able to estimate mean pH to within ±0.5 pH unit.

	England				Scotland				Wales				Northern Ireland			
Classes / country	8				9				6				6			
Scheme/ sample size	Gr	Opt	RS	RC	Gr	Opt	RS	RC	Gr	Opt	RS	RC	Gr	Opt	RS	RC
1000	5	5	5	-	9	9	9	-	2	2	2	-	6	6	6	-
2000	8	8	8	-	9	9	9	-	6	6	6	-	6	6	6	-
4000	8	8	8	8	9	9	9	9	6	6	6	6	6	6	6	6

Notes: The scheme with the best precision and smallest effort highlighted in red/dark shading.

Metals Cu and Zn

For the metal indicators, the data was transformed to carry out the estimation of means. For these indicators, it was necessary to calculate the upper and lower confidence levels of the transformed data then back transform these values to give upper and lower confidence levels in the original units. The width is the difference between these values. The minimum detectable change is (roughly) half this width (roughly because the confidence limits are not symmetric about the mean), so for a 5mg kg^{-1} tolerance the confidence interval width would need to be less than 10 mg kg^{-1}.

The summary for copper (Table 4.4) shows that all land cover classes in England, Wales and Northern Ireland can meet this criterion, mainly for the stratified random and the systematic grid based sampling. For Scotland, eight out of the nine land cover classes do this. The cluster sampling scheme for Northern Ireland performs the worst, with only one class passing the criteria (see Appendix E for further details). For zinc (Table 4.5), only the Scottish sampling scheme produced any reasonable results, with five out of the nine classes meeting the criteria. For Wales, none of the land classes met this, for England one did, increasing to two for Northern Ireland.

Table 4.4 Number of land cover classes that meet the minimum detectable change criteria of 5 mg/kg for copper.

	England				Scotland				Wales				Northern Ireland			
Classes / country	8				9				6				6			
Scheme/ sample size	Gr	Opt	RS	RC	Gr	Opt	RS	RC	Gr	Opt	RS	RC	Gr	Opt	RS	RC
1000	7	7	7		8	8	8		4	4	4		3	3	0	
2000	8	7	8		8	8	8		5	5	5		5	5	3	
4000	8	8	8	7	8	8	8	8	6	5	6	5	6	5	5	1

Notes: The scheme with the best precision and smallest effort are highlighted in red/dark shading. A close second choice is highlighted in blue/light shading.

Table 4.5 Number of land cover classes that meet the minimum detectable change criteria of 5 mg/kg for zinc.

	England				Scotland				Wales				Northern Ireland			
Classes / country	8				9				6				6			
Scheme/ sample size	Gr	Opt	RS	RC	Gr	Opt	RS	RC	Gr	Opt	RS	RC	Gr	Opt	RS	RC
1000	0	0	0		1	1	1		0	0	0		0	0	0	
2000	0	0	1		2	2	2		0	0	0		0	0	0	
4000	0	0	1	0	4	3	5	2	0	0	0	0	1	1	2	0

Notes: The scheme with the best precision and smallest effort are highlighted in red/dark shading.

Bulk density

The only bulk density data that could be used were for class 10 (improved grassland) in Northern Ireland, so the results were only extracted for this class for the other countries. The minimum detectable difference at 95 per cent confidence was calculated, which varied from around 0.01 to 0.06 units. On this basis, it appears that the precision is quite high, however, it must be remembered that these statistics are based on a very limited dataset. For this reason, the data were not used further in the decision-making process. It does however demonstrate that available spatial data can be used to help determine suitable tolerance levels for individual end-user requirements.

4.3.3 Summary of results from sample size calculations based on expected confidence interval width

The results from this analysis have been summarised in Table 4.6, showing the best scheme (in red/underlined) for each indicator on a country basis. In some cases, there was little difference between two schemes and therefore the second best is also given (black/not underlined). For many indicators, the same performance is given by several schemes, and under such circumstances all schemes are given, for example in England the best schemes for pH were Rs, Opt and Gr using the option of 2000 sampling points (on a UK basis). The results for zinc were poor, therefore only the results for Scotland are given. If the level of precision could be achieved with a smaller sample number, then the smaller scheme was selected. As illustrated with the bulk density example, information on the minimum detectable difference for individual indicators would be invaluable for this and for establishing suitable tolerance levels. These could be determined using available spatial and temporal data and should be a priority for UKSIC.

This analysis has shown that the choice of sample design is complex. For each indicator different schemes and intensities perform the best. To add to this complication, it is not the same for all countries. For example, for sampling pH the systematic grid might be chosen, with a sample intensity of 2000 points. This intensity would result in over sampling for Scotland and Northern Ireland where an intensity of 1000 points performs equally well. An intensity of 2000, however, would not be sufficient to estimate the mean SOC levels in Scotland. This would require an increase in sample number to 4000 points. Also, the systematic grid does not fair well in determining SOC change, here the design-based schemes (stratified random sampling and cluster sampling) perform better.

Table 4.6 The best designs for each indicator based on scheme performance and sample number on a country basis.

	England	Scotland	Wales	Northern Ireland
SOC status	**Opt/Gr 1000**	**Gr 4000** RS 4000	**Op & Gr 1000**	**Gr 2000** RS/Op/Gr 4000
SOC change	**RS 4000** RC4000	**RS/RC 4000**	**RS/RC 4000**	**RS/RC4000**
pH	**RS/Opt/Gr 2000**	**RS/Opt/Gr 1000**	**RS/Op/Gr 2000**	**RS/Opt/Gr 1000**
Cu	**RS/Gr 2000**	**RS/Opt/Gr 1000**	**RS/Gr 4000**	**Gr 4000** Opt/Gr 2000
Zn	-	RS 4000	-	-

Note: Numbers refer to the total sample number on a UK basis, not number of samples within a country. Designs in red/bold and on the same line are equal in performance and those below are the second best in performance.

4.3.4 Methods for sample size calculations based on statistical power calculations

This assessment determined the relative performance of the design-based schemes based on statistical power calculations and sample size calculations. Two sets of analyses are presented. The first section analyses SOC, SOC change and pH data from the National Soil Inventories, based on the design-based options established above. The second section presents power calculations from the Countryside Survey on sample size calculations for several UKSIC indicators (reproduced courtesy of CEH and Countryside Survey stakeholders; Emmett *et al*., 2007b). It is important to note that these results are derived from the CS design (not the design-based options explored in this project) and are only included here to illustrate the likely sampling intensities required to report effectively on individual indicators by land use at the country-level.

4.3.5 Results from sample size calculations based on statistical power calculations

The results presented in this section differ from those in the previous section in several ways:

- They are based on raw data, whereas those in the previous section were based on outputs from model runs. Consequently, there are no results for SOC change in Scotland and Northern Ireland based on data from the National Soil Inventories as data were not available at the time of this project.

- Tables 4.7 to 4.11 are based on 80 per cent power. The sample size calculations in the previous section are based on expected confidence interval width corresponding to 50 per cent power; that is, half the time these confidence interval widths will be achieved and half the time they will not be achieved, due to variation in the estimate of the variance

- The results in the previous section are based on the sample allocations in Table 3.3. Here some alternative allocations are considered.

Data from the National Soil Inventories

These calculations assume that a design-based scheme with stratification by land class will be used. Calculations were based on estimates of variances obtained from the NSI data for England and Wales, Scotland and Northern Ireland. As these data were collected on a grid, this will mean that the variances will tend to be over-estimated, leading to a slight under-estimation of the actual power to meet the quality criteria. On the other hand, the fact that the power calculations are based on estimated rather than known variances will cause bias in the other direction and tend to lead to over-estimation of the true power. For these reasons the results are rough approximations but do give some indication of the size of effect that could be detected with different sample sizes. Use of the additional stratification into spatial blocks within Land Cover classes results in a small reduction in the variance and thus a small increase in power in most cases, but as the results are very similar we do not present them here.

The optimal distribution of the sampling effort between land classes will be different for different indicators and will also vary according to the quality criteria, and in particular whether these are expressed in absolute or percentage terms. For example, Table 4.7 shows the estimated sample size that would be required to detect a 20 per cent change in the baseline SOC in each land class in England with 80 per cent power, and the sample size that would be required if the quality criterion is an absolute change of 2.5 per cent SOC (25 g/kg). Both the SOC content and the change in SOC content have higher variance in the land classes with higher SOC content (bog, heath, coniferous woodland, semi-natural grassland) than in those with lower SOC content (arable, improved grassland, broad-leaved woodland). This means that if the quality criterion is expressed in absolute terms, this would suggest that sampling effort should be concentrated in the land classes with higher SOC content, whereas if it is expressed in percentage terms it would suggest that the effort should be concentrated in the classes with low SOC content. If both criteria were required, then sampling should be targeted at the higher number, in this instance towards 20 per cent change in baseline.

Table 4.7 Estimated sample sizes to detect a 20% change in baseline SOC content and to detect a change of 2.5% SOC (25 g kg^{-1}) in land classes in England with 80% power.

		20% of baseline SOC content (d)	Sample sizes to detect changes in SOC of:	
			20% in baseline (d)	2.5%
5	Bog	8.1	12	99
6	Dwarf shrub heath	4.5	69	218
8	Broad-leaved / mixed woodland	1.2	145	34
9	Coniferous woodland	3.3	105	180
10	Improved grassland	1.1	142	28
11	Semi-natural grass	3.7	72	153
14	Arable and horticulture	0.8	146	16
15	Built up areas and gardens	0.9	210	32
	Total Sample Size		901	760

Note: d = tolerance

As it is not possible to allocate samples to land classes in a way that is optimal for all indicators and all quality criteria, it seemed sensible to consider the following schemes:

- Allocation to countries and land classes in proportion to area (but with a minimum sample size in each country/land-class combination) – this was the scheme used in the simulation study to compare model-based and design-based methods.

- Equal numbers of samples in each of the four countries with allocation to land classes within countries in proportion to area (but with a minimum sample size in each country/land-class combination).
- Equal numbers of samples in each country with sampling effort divided equally between the land classes in that country.

Three sampling intensities were used for each of these schemes, giving totals of approximately 1000 (S1), 2000 (S2) and 4000 (S3) samples respectively (Table 4.8). The results of the power calculations for each scheme are given in Tables 4.9–4.11.

Table 4.9 shows the estimated tolerances (d) for SOC status that could be achieved from different sample sizes, allocated by the criteria described above. These results demonstrate, for example, that 111 samples allocated to each land class in Scotland (S3c) would give an estimated tolerance of ± 2.9 per cent for bogs, or ± 5.6 per cent for semi-natural grass. Tolerances for bogs vary from 2.9 to 4.6 per cent across the countries using this sampling intensity.

Table 4.10 shows the estimated change in SOC that could be detected at the different sampling intensities. These results indicate that samples distributed evenly across land uses (the third option above) provide better estimates of change than the other choices, with the best estimate provided from 4000 sampling points.

By comparison, Table 4.11 shows the estimated tolerances for pH status that could be achieved from different sample sizes. In this instance, a tolerance of ± 0.2 pH units maybe achievable from 111 samples in Scotland, equally distributed across all land uses (S3c). However, less frequent sampling (S2c) would achieve tolerances of 0.2 to 0.3 pH units; that is, fewer samples are required to obtain a reliable estimate of soil pH status.

When calculating country-level means from a design-based scheme, the data need to be weighted according to the proportion of the total area of the country in each reporting class. Provided that this is known accurately, the calculation of country-level means presents no particular difficulties. The last line of each section of Tables 4.9 to 4.11 indicates the precision with which country-level means can be estimated. Note that although an equal allocation of samples to reporting classes has benefits in terms of the precision with which means can be estimated for some of the individual classes, there is a small loss of precision in the country-level mean. This can be seen by comparing S1b with S1c, S2b with S2c or S3b with S3c.

Table 4.8 Sample sizes for proposed schemes.

Land class		S1a	S1b	S1c	S2a	S2b	S2c	S3a	S3b	S3c
	England									
5	Bog	10	10	31	20	20	63	40	40	125
6	Dwarf shrub heath	10	10	31	20	20	63	40	40	125
8	Broad-leaved/mixed woodland	26	12	31	53	25	63	106	49	125
9	Coniferous woodland	10	10	31	20	20	63	40	40	125
10	Improved grassland	153	71	31	306	142	63	612	284	125
11	Semi-natural grass	40	18	31	79	37	63	159	74	125
14	Arable and horticulture	206	96	31	412	191	63	824	383	125
15	Built up areas and gardens	48	23	31	97	45	63	194	90	125
	Country Total	503	250	248	1007	500	504	2015	1000	1000
	Northern Ireland									
5	Bog	10	10	42	20	20	83	40	40	167
6	Dwarf shrub heath	10	11	42	20	21	83	40	43	167
9	Coniferous woodland	10	10	42	20	21	83	40	41	167
10	Improved grassland	37	177	42	73	354	83	146	707	167
11	Semi-natural grass	10	32	42	20	64	83	40	129	167
15	Built up areas and gardens	10	10	42	20	20	83	40	40	167
	Country Total	87	250	252	173	500	498	346	1000	1002
	Scotland									
5	Bog	15	12	28	29	23	56	58	47	111
6	Dwarf shrub heath	89	72	28	178	144	56	357	288	111
7	Montane habitats	17	13	28	34	27	56	67	54	111
8	Broad-leaved/mixed woodland	10	10	28	20	20	56	40	40	111
9	Coniferous woodland	37	30	28	75	60	56	150	121	111
10	Improved grassland	51	41	28	102	83	56	204	165	111
11	Semi-natural grass	47	38	28	94	76	56	187	151	111
14	Arable and horticulture	29	24	28	58	47	56	117	94	111
15	Built up areas and gardens	10	10	28	20	20	56	40	40	111
	Country Total	305	250	252	610	500	504	1220	1000	999
	Wales									
6	Dwarf shrub heath	10	10	42	20	20	83	40	40	167
8	Broad-leaved/mixed woodland	10	10	42	20	20	83	40	40	167
9	Coniferous woodland	10	17	42	20	35	83	40	69	167
10	Improved grassland	43	133	42	85	266	83	170	532	167
11	Semi-natural grass	22	70	42	45	139	83	89	279	167
15	Built up areas and gardens	10	10	42	20	20	83	40	40	167
	Country Total	105	250	252	210	500	498	419	1000	1002
	UK Total	1000	1000	1004	2000	2000	2004	4000	4000	4003

Notes: UK sampling numbers: 1000 (S1), 2000 (S2) and 4000 (S3). a = sample number allocation to countries and land classes in proportion to area; b = equal numbers of samples in each of the four countries with allocation to land classes within countries in proportion to area; c = equal numbers of samples in each country with sampling effort divided equally between the land classes in that country

Table 4.9 Estimated tolerances (*d*) such that there is an 80% probability that the width of the 95% confidence interval for % SOC will be less than ± *d*.

Land class		Mean	S1a	S1b	S1c	S2a	S2b	S2c	S3a	S3b	S3c
	England										
5	Bog	43.2	14.6	14.6	7.6	9.7	9.7	5.3	6.7	6.7	3.7
6	Dwarf shrub heath	25.4	18.4	18.4	9.7	12.2	12.2	6.7	8.4	8.4	4.7
8	Broad-leaved/mixed woodland	5.1	3.5	5.4	3.2	2.4	3.5	2.2	1.7	2.5	1.6
9	Coniferous woodland	13.7	16.7	16.7	8.7	11.1	11.1	6.0	7.6	7.6	4.3
10	Improved grassland	4.8	1.1	1.7	2.6	0.8	1.2	1.8	0.6	0.9	1.3
11	Semi-natural grass	14.7	7.3	11.2	8.3	5.1	7.6	5.8	3.6	5.3	4.1
14	Arable and horticulture	3.6	0.9	1.3	2.2	0.6	0.9	1.5	0.5	0.7	1.1
15	Built up areas and gardens	4.5	1.5	2.2	1.9	1.1	1.5	1.3	0.8	1.1	0.9
	Country mean	6.0	0.9	1.3	1.4	0.7	0.9	1.0	0.5	0.7	0.7
	Northern Ireland										
5	Bog	37.4	15.3	15.3	6.8	10.2	10.2	4.8	7.0	7.0	3.4
6	Dwarf shrub heath	30.7	16.7	15.8	7.5	11.1	10.8	5.3	7.7	7.4	3.7
9	Coniferous woodland	33.0	15.9	15.9	7.1	10.6	10.3	5.0	7.3	7.2	3.5
10	Improved grassland	5.8	2.5	1.1	2.3	1.8	0.8	1.7	1.3	0.6	1.2
11	Semi-natural grass	20.7	17.9	9.2	8.0	11.9	6.4	5.6	8.2	4.5	3.9
15	Built up areas and gardens	4.1									
	Country mean	11.3	3.0	1.8	2.0	2.1	1.3	1.5	1.5	0.9	1.0
	Scotland										
5	Bog	49.9	8.4	9.6	6.0	5.9	6.6	4.2	4.1	4.6	2.9
6	Dwarf shrub heath	40.0	5.0	5.6	9.2	3.6	4.0	6.4	2.5	2.8	4.5
7	Montane habitats	32.3	13.9	16.3	10.6	9.5	10.8	7.3	6.7	7.5	5.2
8	Broad-leaved/mixed woodland	17.4	19.1	19.1	10.6	12.7	12.7	7.4	8.8	8.8	5.2
9	Coniferous woodland	33.6	9.5	10.6	11.0	6.6	7.4	7.6	4.6	5.2	5.4
10	Improved grassland	10.2	5.1	5.8	7.0	3.6	4.0	4.9	2.6	2.8	3.5
11	Semi-natural grass	27.6	8.6	9.6	11.3	6.0	6.7	7.9	4.3	4.8	5.6
14	Arable and horticulture	6.9	6.2	6.9	6.3	4.3	4.8	4.4	3.0	3.4	3.1
15	Built up areas and gardens	5.5									
	Country mean	27.9	2.7	3.1	3.8	2.0	2.2	2.7	1.4	1.5	1.9
	Wales										
6	Dwarf shrub heath	25.5	20.7	20.7	9.3	13.8	13.8	6.5	9.5	9.5	4.6
8	Broad-leaved/mixed woodland	6.8	4.9	4.9	2.2	3.3	3.3	1.6	2.3	2.3	1.1
9	Coniferous woodland	17.2	16.2	11.8	7.2	10.8	8.0	5.1	7.4	5.6	3.6
10	Improved grassland	5.6	2.6	1.5	2.6	1.8	1.0	1.9	1.3	0.8	1.3
11	Semi-natural grass	17.5	10.5	5.7	7.5	7.2	4.1	5.3	5.1	2.9	3.7
15	Built up areas and gardens	6.4	3.6	3.6	1.6	2.4	2.4	1.1	1.7	1.7	0.8
	Country mean	10.9	3.5	2.1	2.6	2.5	1.5	1.9	1.8	1.1	1.3

Notes: UK sampling numbers: 1000 (S1), 2000 (S2) and 4000 (S3). a = sample number allocation to countries and land classes in proportion to area; b = equal numbers of samples in each of the four countries with allocation to land classes within countries in proportion to area; c = equal numbers of samples in each country with sampling effort divided equally between the land classes in that country. Results are not presented for built up areas and gardens in Northern Ireland and Scotland because they are unreliable as there were only two observations in this land class

Table 4.10 Estimated absolute change in % SOC that can be detected with 80% probability at the 5% significance level.

Land class		S1a	S1b	S1c	S2a	S2b	S2c	S3a	S3b	S3c
	England									
5	Bog	8.8	8.8	4.6	5.9	5.9	3.2	4.0	4.0	2.3
6	Dwarf shrub heath	13.1	13.1	6.9	8.7	8.7	4.7	6.0	6.0	3.4
8	Broad-leaved/mixed woodland	2.9	4.5	2.7	2.0	3.0	1.9	1.4	2.1	1.3
9	Coniferous woodland	11.9	11.9	6.2	7.9	7.9	4.3	5.5	5.5	3.1
10	Improved grassland	1.1	1.6	2.4	0.8	1.1	1.7	0.6	0.8	1.2
11	Semi-natural grass	5.0	7.7	5.8	3.5	5.2	4.0	2.5	3.7	2.8
14	Arable and horticulture	0.7	1.0	1.7	0.5	0.7	1.2	0.5	0.5	0.9
15	Built up areas and gardens	2.0	3.0	2.6	1.4	2.1	1.8	1.0	1.5	1.3
	Country mean	0.7	1.0	1.2	0.5	0.7	0.8	0.4	0.5	0.6
	Wales									
6	Dwarf shrub heath	9.3	9.3	4.2	6.2	6.2	3.0	4.3	4.3	2.1
8	Broad-leaved/ mixed woodland	2.3	2.3	1.1	1.6	1.6	0.8	1.1	1.1	0.6
9	Coniferous woodland	11.0	8.0	4.9	7.3	5.4	3.5	5.0	3.8	2.4
10	Improved grassland	2.4	1.3	2.4	1.7	1.0	1.7	1.2	0.7	1.2
11	Semi-natural grass	6.9	3.7	4.9	4.7	2.7	3.4	3.3	1.9	2.4
15	Built up areas and gardens	3.8	3.8	1.7	2.6	2.6	1.2	1.8	1.8	0.9
	Country mean	2.4	1.5	1.9	1.7	1.0	1.4	1.2	0.8	1.0

Note: Tables are not provided for Scotland and Northern Ireland as no change data were available for these countries.

Table 4.11 Estimated tolerances (*d*) such that there is an 80% probability that the width of the 95% confidence interval for pH will be less than ± *d*.

Land class		mean	S1a	S1b	S1c	S2a	S2b	S2c	S3a	S3b	S3c
	England										
5	Bog	3.6	0.6	0.6	0.3	0.4	0.4	0.2	0.3	0.3	0.2
6	Dwarf shrub heath	4.0	0.7	0.7	0.4	0.5	0.5	0.3	0.4	0.4	0.2
8	Broad-leaved / mixed woodland	5.6	0.8	1.2	0.7	0.6	0.8	0.5	0.4	0.6	0.4
9	Coniferous woodland	4.7	1.3	1.3	0.7	0.9	0.9	0.5	0.6	0.6	0.4
10	Improved grassland	5.8	0.3	0.4	0.6	0.2	0.3	0.4	0.2	0.2	0.3
11	Semi-natural grass	5.1	0.7	1.0	0.8	0.5	0.7	0.5	0.4	0.5	0.4
14	Arable and horticulture	6.8	0.3	0.3	0.6	0.2	0.3	0.4	0.1	0.2	0.3
15	Built up areas and gardens	6.3	0.5	0.8	0.6	0.4	0.5	0.5	0.3	0.4	0.3
	Country mean	6.1	0.2	0.2	0.3	0.1	0.2	0.2	0.1	0.1	0.2
	Northern Ireland										
5	Bog	4.9	0.9	0.9	0.4	0.6	0.6	0.3	0.4	0.4	0.2
6	Dwarf shrub heath	5.0	0.9	0.8	0.4	0.6	0.6	0.3	0.4	0.4	0.2
9	Coniferous woodland	4.8	0.8	0.8	0.4	0.5	0.5	0.3	0.4	0.4	0.2
10	Improved grassland	5.8	0.3	0.2	0.3	0.2	0.1	0.2	0.2	0.1	0.2
11	Semi-natural grass	5.3	0.7	0.4	0.4	0.5	0.3	0.3	0.4	0.2	0.2
15	Built up areas and gardens	5.9	0.6	0.6	0.3	0.4	0.4	0.2	0.3	0.3	0.2
	Country mean	5.6	0.2	0.2	0.2	0.2	0.1	0.2	0.1	0.1	0.1
	Scotland										
5	Bog	3.9	0.4	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2
6	Dwarf shrub heath	4.2	0.2	0.2	0.3	0.2	0.2	0.2	0.1	0.1	0.2
7	Montane habitats	4.1	0.4	0.5	0.3	0.3	0.3	0.2	0.2	0.2	0.2
8	Broad-leaved / mixed woodland	5.0	0.9	0.9	0.5	0.6	0.6	0.4	0.5	0.5	0.3
9	Coniferous woodland	4.2	0.4	0.4	0.4	0.3	0.3	0.3	0.2	0.2	0.2
10	Improved grassland	5.4	0.4	0.4	0.5	0.3	0.3	0.3	0.2	0.2	0.3
11	Semi-natural grass	4.5	0.4	0.4	0.5	0.3	0.3	0.3	0.2	0.2	0.2
14	Arable and horticulture	5.7	0.5	0.5	0.5	0.3	0.4	0.3	0.2	0.3	0.2
15	Built up areas and gardens	6.0									
	Country mean	4.6	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1
	Wales										
6	Dwarf shrub heath	4.2	0.9	0.9	0.4	0.6	0.6	0.3	0.4	0.4	0.2
8	Broad-leaved / mixed woodland	4.6	0.7	0.7	0.3	0.5	0.5	0.2	0.3	0.3	0.2
9	Coniferous woodland	4.3	0.8	0.6	0.4	0.5	0.4	0.3	0.4	0.3	0.2
10	Improved grassland	5.3	0.4	0.2	0.4	0.3	0.2	0.3	0.2	0.1	0.2
11	Semi-natural grass	4.6	0.5	0.3	0.4	0.4	0.2	0.3	0.3	0.2	0.2
15	Built up areas and gardens	5.3	1.1	1.1	0.5	0.7	0.7	0.4	0.5	0.5	0.3
	Country mean	5.0	0.3	0.2	0.3	0.2	0.1	0.2	0.2	0.1	0.2

Notes: Results are not presented for built up areas and gardens in Scotland because they are unreliable as there are only two observations in this land class.

Data from Countryside Survey

In preparation for Countryside Survey 2007, CEH carried out a series of statistical analyses to assess the effectiveness of the re-sampling scheme to estimate changes in concentrations of soil carbon, soil pH, heavy metals and organic compounds (polycyclic aromatic hydrocarbons – PAHs and polychlorinated biphenyls - PCBs). This was done to assist the CS Soils Topic Steering Group to identify the analytes and products that would be included in the coming survey. Full details of the analyses and results are available from CEH (Emmett *et al*., 2007b). A summary from this report is presented here for the power analyses undertaken of the sampling requirements to reliably detect change in soil pH and soil carbon from Loss on Ignition (LOI) at the country level. The original Ecological Survey of Great Britain 1978 contained 256 squares, each of which contained 5 X-plots. In CS2000, the number of squares was 569, but soil analyses in CS2000 were limited to the original 256 squares (Black *et al*., 2000). Each square contains 5 X-plots, giving a maximum of 1280 samples; see Table 4.12.

Table 4.12 Summary of sample numbers and 1 km squares within the original 1978 survey that were subsequently re-sampled for soils in CS2000.

Level	Samples	Squares
England	620	124
Wales	120	24
Scotland	540	108
Total	1280	256

Note: Current Countryside Survey maximum sample N = 3259 (650 squares)

The power analyses were based on the available data from 1978 and 2000. Estimates of change were obtained as weighted averages using the ITE Land Classification as strata. These estimates and their standard errors were then used to provide a power analysis for the ability to detect change from CS2000 to CS2007. This uses assumptions of normality to estimate the probability of detecting changes of specified size at a variety of significance levels. Altering the sampling sizes used in the power calculations allowed the calculation of the increase in power possible through an increase in the number of sample squares.

The results of the power analysis for soil pH are shown in Table 4.13. For Wales, for example, there is 98.3 per cent chance of detecting a 5 per cent change in soil pH at the 1 per cent significance level, based on the 256 squares measured in 1978 and in CS2000. Overall the results indicate that no more squares beyond the original 256 sampled in 1978 are required for reliable reporting of country level changes in soil pH.

However, there are some very important caveats on the interpretation of this analysis. The increase in pH from 1978 to CS2000 was relatively consistent across the whole of the UK. As a result, the measurements of change have small standard errors and hence the power to detect change is high, even with the small sample sizes. All three countries show significant change. The apparently greater change in Wales may be a reflection of the much smaller sample size including some influential squares.

It is unlikely that the change in soil pH between CS2000, CS2007 and future surveys will be as consistent across the country in either direction or magnitude. The interval between the measurements will probably be smaller (8-9 years compared to 20-21 years) and the change in acid deposition (one of the main drivers for change) during the last eight years has been less than between 1978 and CS2000 and is likely to become more regionally variable into the future. Therefore, whilst the results of the power analysis might suggest that change in soil pH can be detected reliably at the country level with data from 256 sample squares (that is,1280 samples), this result is influenced by the nature of the pH change detected between 1978 and CS2000. Given the uncertainties in the expected pH change between CS2000, CS2007 and into the future, soil pH will be determined on the X plots from all 1 km squares visited in CS2007 to safeguard future country-level reporting of soil pH change (approximately 3500 sampling locations).

Table 4.13 Results of the power analysis to detect change in soil pH at the individual country level based on data from 1978 and CS2000.

		Percentage change in pH			
	Significance	**5%**	**10%**	**20%**	**30%**
England	1%	99.9	100	100	100
	5%	100.0	100	100	100
	10%	100.0	100	100	100
Scotland	1%	99.7	100	100	100
	5%	99.9	100	100	100
	10%	100.0	100	100	100
Wales	1%	98.3	100	100	100
	5%	99.4	100	100	100
	10%	99.8	100	100	100

Table 4.14 Power to detect various degrees of change in LOI for England, Scotland and Wales.

		Percentage change in LOI			
	Significance	**5%**	**10%**	**20%**	**30%**
England	1%	12.3	50.3	99.0	100.0
	5%	21.4	64.6	99.7	100.0
	10%	31.6	75.5	99.9	100.0
Scotland	1%	24.1	82.1	100.0	100.0
	5%	36.8	90.1	100.0	100.0
	10%	49.1	94.5	100.0	100.0
Wales	1%	3.6	10.0	40.6	79.0
	5%	7.5	18.0	55.1	88.0
	10%	13.1	27.4	67.2	93.2

The results of the power analysis for LOI are shown in Table 4.14. These indicate that the current sample sizes enable changes of about 10 per cent to be detected with reasonable power in Scotland and England. For example, the analysis shows that the number of squares sampled for soils in CS2000 in England gives a 64.6 per cent chance of observing a 10 per cent change in LOI with a significance of 5 per cent (the usual level below which results are not considered significant). However, in Wales the soil sample size is too small to detect any reasonable level of change with any certainty. In Wales, the number of squares previously analysed for soils only yields a 18 per cent chance of observing a 5 per cent change in LOI. Hence, the number of squares in CS2000 is insufficient to allow country-level reporting for Wales. Table 4.15 summarises the statistical power of various sample sizes in Wales. Whilst 20 squares have previously been sampled for soils in Wales, there were a total of 65 squares in Wales in CS2000. However, to enable reasonable reporting for Wales separately in

CS2007, it has been recommended that Wales has a total of 124 squares in CS2007. If all these 124 squares were sampled for soils, there would be a 72.5 per cent chance of detecting a 10 per cent change in LOI at 5 per cent significance.

Table 4.15 Power to detect various degrees of change with increased sample sizes in Wales.

		Percentage change in LOI			
Sample size	**Significance**	**5%**	**10%**	**20%**	**30%**
100 (20)	1%	3.6	10.0	40.6	79.0
(1978/2000)	5%	7.5	18.0	55.1	88.0
	10%	13.1	27.4	67.2	93.2
325 (65)	1%	8.3	32.9	92.5	100.0
(current)	5%	15.4	46.9	96.5	100.0
	10%	24.1	59.4	98.3	100.0
450 (90)	1%	11.2	45.6	98.2	100.0
	5%	19.7	60.1	99.3	100.0
	10%	29.6	71.6	99.7	100.0
600 (120)	1%	14.8	59.2	99.7	100.0
(proposed)	5%	24.8	72.5	99.9	100.0
	10%	35.7	82.0	100.0	100.0

Comparison of power analyses

There was considerable consistency between the two sets of power analyses for soil pH and SOC status and soil carbon change. The results suggest that, given the quality criteria used, both soil pH status and change could be assessed reliably, for the different land uses and at the country-level, from a sample size between 500 and 600 in both England and Scotland, 120 to 200 samples in Wales and 200 in Northern Ireland. Detection of a 5 to 10 per cent change in SOC (equivalent to 10 to 20 per cent LOI) at 5 per cent significance levels, with 80 per cent confidence, would also require 500 to 600 samples in both England and Scotland. However, Wales would require more intensive samples using at least 480 samples. With no change data from Northern Ireland, the results indicate that 200 samples would give a reliable estimate of country-level SOC status but samples numbers of 500 or more would give more reliable estimates of status for individual land uses.

At the country level, the allocation of sampling intensities to establish reliable statistics for indicators by land use within countries were similar to those for country-level statistics, which is reflected in similar tolerance levels between the two options. Where these options differ are in the tolerances achievable for land uses within countries. Tolerances are much smaller for the allocation of land use within country.

These power analyses were used to assess the performance of individual design options by using a set of quality criteria determined by the project team to illustrate the performance of the different sampling options. They are not definitive quality criteria. Ultimately UKSIC will need to determine what levels of tolerance are acceptable for each indicator and reporting class in order to determine the optimal sampling effort.

4.4 Costs and resource implications

Costs were determined for each country separately with a 20 per cent sampling contingency included. These were determined using the experience of planning large-scale surveys and monitoring schemes, along with practical knowledge from members of the consortium. The difference between the costs for the individual countries can be linked to the sample number. To help understand these differences, the numbers for each country at a given sampling intensity are shown in Table 4.16. These figures are based on Table 3.3, Section 3.

Table 4.16 Sampling points within a country based on sampling intensities of 1000, 2000 and 4000 with allocation to countries in proportion to their area

	1000	2000	4000
England	503	1007	2015
Scotland	305	610	1220
Wales	105	210	419
Northern Ireland	87	173	346

The costs for each sampling scheme have been summarised in Tables 4.17 to 4.20. Three different options are shown:

- Option 1 includes a bulked soil sample with two soil cores (one for bulk density and one for nitrogen mineralisation)
- Option 2 is the same as Option 1 but with an extra core for soil chemistry, to make it comparable to all existing schemes
- Option 3, as for option 2, but with an additional sample for 0-7.5 cm from grasslands

The costs within each option include:

- Project co-ordinator.
- Field survey effort – based on two people per team for health and safety purposes and travel and subsistence costs.
- Basic site characteristics.
- Measurement for 13 indicators - Soil organic carbon (which includes total N and C:N), pH, Olsen P, Aqua regia extractable metals (copper, cadmium, zinc, nickel), Extractable magnesium and potassium, soil bulk density and mineralisable nitrogen.
- Archiving (10 years only)- for air dried sieved soil.
- Data management.
- Statistical analysis.
- Reporting.

It does not, however, include costs for additional supplementary information. It should be noted that the costs are for the first survey and include one-off start up costs (such as setting up the database), which will not be required for subsequent surveys. It is likely that future monitoring events would require similar levels of funding to rework existing databases to incorporate new data and therefore the costs should be taken as indicative of any monitoring event.

The differences in cost between the different sampling schemes can be related to the different field survey effort. For example, an assumption was made that two to three samples would be taken per day for the systematic grid design, whereas for the cluster analysis, where several samples are close together, this was increased to four samples per day. In general, the field survey accounts for over half the overall costs and involves a large staff effort. For instance, for the grid sampling with an intensity of 4000 points, over 1700 staff days would be required in England alone.

Table 4.21 illustrates the cost for Option 1 if only the canary indicators were analysed (soil organic carbon, pH, total copper and zinc). The values in red give the cost reduction from the original cost (13 indicators). This reduction is the same for each scheme; it changes for the sample number only. For example, for England the cost of the scheme is reduced by £0.22 million for 4000 samples, and by £0.06 million for 1000 samples. Northern Ireland, which shows the smallest reduction, shows a decrease in cost by £0.05 million for 4000 samples and £0.02 million for 1000 samples.

Table 4.17 Summarised costs for the different sampling schemes in England

		Sampling points on a UK basis		
Options	**Scheme details**	**1000**	**2000**	**4000**
Option 1a	Random sampling, auger sample only, bulk density and N min cores	£371,637	£596,633	£1,046,625
Option 1b	Optimised sampling, auger sample only, bulk density and N min cores	£352,240	£557,800	£968,920
Option 1c	Grid sampling, auger sample only, bulk density and N min cores	£398,793	£650,999	£1,155,410
Option 1d	Cluster sampling, auger sample only, bulk density and N min cores			£910,642
Option 2a	Random sampling, auger sample and core, bulk density and N min cores	£426,224	£697,348	£1,239,597
Option 2b	Optimised sampling, auger sample and core, bulk density and N min cores	£406,827	£658,516	£1,161,893
Option 2c	Grid sampling, auger sample and core, bulk density and N min cores	£453,380	£751,714	£1,348,383
Option 2d	Cluster sampling, auger sample and core, bulk density and N min cores			£1,103,615
Option 3a	Random sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£434,654	£714,164	£1,273,273
Option 3b	Optimised sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£415,257	£675,332	£1,195,569
Option 3c	Grid sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£461,810	£768,530	£1,382,059
Option 3d	Cluster sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores			£1,137,291

Table 4.18 Summarised costs for the different sampling schemes in Scotland

Options	Scheme details	Sampling points on a UK basis		
		1000	2000	4000
Option 1a	Random sampling, auger sample only, bulk density and N min cores	£281,084	£417,646	£690,473
Option 1b	Optimised sampling, auger sample only, bulk density and N min cores	£269,323	£394,122	£643,427
Option 1c	Grid sampling, auger sample only, bulk density and N min cores	£297,551	£450,578	£756,339
Option 1d	Cluster sampling, auger sample only, bulk density and N min cores			£608,141
Option 2a	Random sampling, auger sample and core, bulk density and N min cores	£317,678	£482,283	£811,196
Option 2b	Optimised sampling, auger sample and core, bulk density and N min cores	£305,916	£458,759	£764,149
Option 2c	Grid sampling, auger sample and core, bulk density and N min cores	£334,144	£515,215	£877,061
Option 2d	Cluster sampling, auger sample and core, bulk density and N min cores			£728,864
Option 3a	Random sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£323,177	£493,268	£833,149
Option 3b	Optimised sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£311,415	£469,745	£786,103
Option 3c	Grid sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£339,643	£526,201	£899,015
Option 3d	Cluster sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores			£750,818

Table 4.19 Summarised costs for the different sampling schemes in Wales

Options	Scheme details	Sampling points on a UK basis 1000	 2000	 4000
Option 1a	Random sampling, auger sample only, bulk density and N min cores	£189,538	£236,633	£330,273
Option 1b	Optimised sampling, auger sample only, bulk density and N min cores	£185,489	£228,535	£314,115
Option 1c	Grid sampling, auger sample only, bulk density and N min cores	£195,207	£247,970	£352,894
Option 1d	Cluster sampling, auger sample only, bulk density and N min cores			£301,997
Option 2a	Random sampling, auger sample and core, bulk density and N min cores	£207,783	£264,573	£377,511
Option 2b	Optimised sampling, auger sample and core, bulk density and N min cores	£203,734	£256,475	£361,353
Option 2c	Grid sampling, auger sample and core, bulk density and N min cores	£213,452	£275,911	£400,132
Option 2d	Cluster sampling, auger sample and core, bulk density and N min cores			£349,235
Option 3a	Random sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£212,264	£273,523	£395,392
Option 3b	Optimised sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£208,215	£265,425	£379,234
Option 3c	Grid sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£217,933	£284,861	£418,013
Option 3d	Cluster sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores			£367,116

Table 4.20 Summarised costs for the different sampling schemes in Northern Ireland

Options	Scheme details	Sampling points on a UK basis		
		1000	**2000**	**4000**
Option 1a	Random sampling, auger sample only, bulk density and N min cores	£181,009	£219,564	£297,038
Option 1b	Optimised sampling, auger sample only, bulk density and N min cores	£177,655	£212,893	£283,696
Option 1c	Grid sampling, auger sample only, bulk density and N min cores	£185,706	£228,904	£315,718
Option 1d	Cluster sampling, auger sample only, bulk density and N min cores			£273,689
Option 2a	Random sampling, auger sample and core, bulk density and N min cores	£197,584	£244,070	£337,500
Option 2b	Optimised sampling, auger sample and core, bulk density and N min cores	£194,229	£237,398	£324,157
Option 2c	Grid sampling, auger sample and core, bulk density and N min cores	£202,281	£253,410	£356,180
Option 2d	Cluster sampling, auger sample and core, bulk density and N min cores			£314,150
Option 3a	Random sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£201,510	£251,878	£353,129
Option 3b	Optimised sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£198,155	£245,206	£339,786
Option 3c	Grid sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores	£206,207	£261,218	£371,809
Option 3d	Cluster sampling, auger sample and core, auger for sample grasslands, bulk density and N min cores			£329,779

Table 4.21 Costings for the canary indicators with option 1.

Options	Scheme	Scheme details	Sampling points on a UK basis		
			1000	2000	4000
England	Option 1a	Random sampling, auger sample only, bulk density and N min cores	£307,778	£478,715	£820,588
	Option 1b	Optimised sampling, auger sample only, bulk density and N min cores	£288,381	£439,882	£742,884
	Option 1c	Grid sampling, auger sample only, bulk density and N min cores	£334,934	£533,081	£929,374
	Option 1d	Cluster sampling, auger sample only, bulk density and N min cores			£684,605
			£63,859	£117,918	£226,037
Scotland	Option 1a	Random sampling, auger sample only, bulk density and N min cores	£238,857	£342,575	£549,718
	Option 1b	Optimised sampling, auger sample only, bulk density and N min cores	£227,095	£319,052	£502,671
	Option 1c	Grid sampling, auger sample only, bulk density and N min cores	£255,323	£375,508	£615,583
	Option 1d	Cluster sampling, auger sample only, bulk density and N min cores			£467,386.33
			£42,228	£75,071	£140,755
Wales	Option 1a	Random sampling, auger sample only, bulk density and N min cores	£169,327	£205,075	£276,128
	Option 1b	Optimised sampling, auger sample only, bulk density and N min cores	£165,278	£196,976	£259,970
	Option 1c	Grid sampling, auger sample only, bulk density and N min cores	£174,996	£216,412	£298,749
	Option 1d	Cluster sampling, auger sample only, bulk density and N min cores			£247,852
			£20,211	£31,558	£54,145
Northern Ireland	Option 1a	Random sampling, auger sample only, bulk density and N min cores	£162,857	£192,127	£250,924
	Option 1b	Optimised sampling, auger sample only, bulk density and N min cores	£159,503	£185,456	£237,581
	Option 1c	Grid sampling, auger sample only, bulk density and N min cores	£167,554	£201,467	£269,604
	Option 1d	Cluster sampling, auger sample only, bulk density and N min cores			£227,574
			£18,152	£27,437	£46,115

Note: Values in red are the cost reductions compared to the original costs for 13 indicators.

4.5 Comprehensive assessment in a Decision Support Framework

In the previous sections the sampling scheme has been evaluated, both in terms of the design and the ability to meet set criteria, and the costs for each scheme have been determined. This information has been brought together and summarised as an aid to the decision making process. This is shown both for a unified UK scheme, and for individual countries (Tables 4.22).

In order to evaluate the schemes, the percentage of land classes that meet the criteria for each indicator in each country has been determined. This is based on the results in Tables 4.1 to 4.5. For example, for the stratified random sampling in England, for 4000 sampling points, eight out of the eight land classes meet the criteria for SOC status, therefore it has a value of 100 per cent. If the sampling is reduced to 2000 points, then only seven out of eight land classes meet the criteria so it is given a value of 88 per cent.

Using this information it is easy to see how well a particular indicator will be measured across all schemes. For instance, most schemes enable a reliable estimate for soil pH (that is, most have values of 100 per cent). In comparison, neither of the model-based schemes are particularly suitable for determining SOC change, the design-based approaches with 4000 samples are better for this.

If several sample intensities are suitable for an indicator, the columns to the right can be examined, which show what cost category the scheme lies within. Different categories were used for each country due to the costs being of a different order of magnitude, the exception being Wales and Northern Ireland where the same categories were used (Table 4.23).

Table 4.22 Soil monitoring decision matrix for a unified UK scheme

Factors to be considered in design of scheme									Indicators					Costs for different sampling options			Summary	
Basis	Risk of bias	Simplicity	Flexibility	Model assumptions	Scheme	Country	Overall sample no.	No. of samples per country	SOC status	SOC change	pH	Cu	Zn	Auger bulked + 2 cores (option 1) (£M)	Auger bulked + 3 cores (Option 2) (£M)	Auger bulked + 3 cores + grassland auger (Option 3) (£M)	Total Indicator score (max 500)	Total scores for design (max 2000 with) 4000 samples
Design	unbiased	Statistics are straight forward to compute	Less flexible, although some with respect to analysis post sampling	No model assumptions are required. Distributional ssumptions are required to derive confidence intervals	Stratified random	England	1000	503	63	25	63	88	0	<0.5	<0.5	<0.5	238	1536
							2000	1007	88	63	100	100	13	0.5-0.7	0.5-0.7	0.5-0.7	363	
							4000	2015	100	88	100	100	13	>1.0	>1.0	>1.0	**400**	
						Scotland	1000	305	25	75	100	89	11	>0.3	0.3-0.5	0.3-0.5	300	
							2000	610	63	75	100	89	22	0.3-0.5	0.3-0.5	0.3-0.5	349	
							4000	1220	75	100	100	89	56	0.5-0.7	>0.7	>0.7	**419**	
						Wales	1000	105	67	0	33	67	0	<0.2	0.2-0.25	0.2-0.25	167	
							2000	210	100	0	100	83	0	0.2-0.25	0.25-0.3	0.25-0.3	283	
							4000	419	100	33	100	100	0	>0.3	>0.3	>0.3	**333**	
						Northern Ireland	1000	87	17	0	100	0	0	<0.2	>0.2	0.2-0.25	117	
							2000	173	33	33	100	50	0	0.2-0.25	0.2-0.25	0.25-0.3	217	
							4000	346	100	67	100	83	33	0.25-0.3	>0.3	>0.3	**383**	
					Cluster	England	1000	503						na	na	na	0	1303
							2000	1007						na	na	na	0	
							4000	2015	100	75	100	88	0	0.7-1.0	>1.0	>1.0	**363**	
						Scotland	1000	305						na	na	na	0	
							2000	610						na	na	na	0	
							4000	1220	63	100	100	89	22	0.5-0.7	>0.7	>0.7	**374**	
						Wales	1000	105						na	na	na	0	
							2000	210						na	na	na	0	
							4000	419	100	33	100	83	0	>0.3	>0.3	>0.3	**317**	
						Northern Ireland	1000	87						na	na	na	0	
							2000	173						na	na	na	0	
							4000	346	67	67	100	17	0	0.25-0.3	>0.3	>0.3	**250**	
Model	Small risk but unlikely at national scale	More complex approaches maybe required	Greater flexibility, can be used to detect unanticipated change	Assumptions are required and maybe open to criticsm	Optimised grid	England	1000	503	100	0	63	88	0	<0.5	<0.5	<0.5	250	1322
							2000	1007	100	13	100	88	0	0.5-0.7	0.5-0.7	0.5-0.7	300	
							4000	2015	100	38	100	100	0	0.7-1.0	>1.0	>1.0	**338**	
						Scotland	1000	305	13	13	100	89	11	<0.3	0.3-0.5	0.3-0.5	225	
							2000	610	50	38	100	89	22	0.3-0.5	0.3-0.5	0.3-0.5	299	
							4000	1220	63	50	100	89	33	0.5-0.7	>0.7	>0.7	**335**	
						Wales	1000	105	100	0	33	67	0	<0.2	0.2-0.25	0.2-0.25	200	
							2000	210	100	0	100	83	0	0.2-0.25	0.25-0.3	0.25-0.3	283	
							4000	419	100	17	100	83	0	>0.3	>0.3	>0.3	**300**	
						Northern Ireland	1000	87	17	0	100	0	0	<0.2	<0.2	<0.2	117	
							2000	173	17	50	100	83	0	0.2-0.25	0.2-0.25	0.2-0.25	250	
							4000	346	100	50	100	83	17	0.25-0.3	>0.3	>0.3	**350**	
					Systematic grid	England	1000	503	100	0	63	88	0	<0.5	<0.5	<0.5	250	1400
							2000	1007	100	25	100	100	0	0.5-0.7	0.5-0.7	0.5-0.7	325	
							4000	2015	100	63	100	100	0	>1.0	>1.0	>1.0	**363**	
						Scotland	1000	305	13	13	100	89	11	<0.3	0.3-0.5	0.3-0.5	225	
							2000	610	63	38	100	89	22	0.3-0.5	0.5-0.7	0.5-0.7	311	
							4000	1220	88	50	100	89	44	>0.7	>0.7	>0.7	**371**	
						Wales	1000	105	100	0	33	67	0	<0.2	0.2-0.25	0.2-0.25	200	
							2000	210	100	0	100	83	0	0.2-0.25	0.25-0.3	0.25-0.3	283	
							4000	419	100	0	100	100	0	>0.3	>0.3	>0.3	**300**	
						Northern Ireland	1000	87	17	0	100	50	0	<0.2	0.2-0.25	0.2-0.25	167	
							2000	173	100	17	100	83	0	0.2-0.25	0.25-0.3	0.25-0.3	300	
							4000	346	100	50	100	100	17	>0.3	>0.3	>0.3	**367**	

Table 4.23 Cost categories used in the decision matrix (£ Millions)

England	Scotland	Wales	Northern Ireland
< 0.5	< 0.3	< 0.2	< 0.2
0.5 -0.7	0.3 -0.5	0.2 -0.25	0.2 -0.25
0.7 – 0.1	0.5 – 0.7	0.25 – 0.3	0.25 – 0.3
>1.0	>0.7	>0.3	>0.3

Assessment of unified UK scheme

The final two columns in Table 4.22 summarise the results for all indicators, to help decide which scheme performs best overall. In the first of these columns, the sum for all canary indicators (SOC status, SOC change, pH, copper and zinc) has been determined for each scheme and the maximum score (out of a total of 500) is given in red. From this, it appears that a sample intensity of 4000 gives the highest score. The final column gives the sum of the scores (maximum of 2000) for each scheme based on an intensity of 4000 points. This shows that the stratified random design scores highest with a value of 1536. The systematic grid gives a score of 1400, with the optimised grid and cluster sampling performing less well.

The top two schemes for the UK are therefore model- and design-based schemes. Both have similar outline costs for 4000 samples at a UK level (>£2.3 million). The main advantage of the model-based scheme is its flexibility, whereas the disadvantage is the complexity of the statistical analysis. In comparison, the design-based model is less flexible, but easier to analyse statistically.

Assessment of country based schemes

Examining the information on a country basis also highlights the fact that cluster sampling performs better for England, Scotland and Wales than suggested by looking at the UK as a whole. This is because cluster sampling does not perform well in Northern Ireland (mainly due to a low value for copper), and this lowered the overall score at a UK level. Costs do not vary greatly between the different design options at the country-level. The optimised grid generally displays the lowest costs, while stratified random and grid sampling are the most costly and have similar costs. Country-level costs would obviously be rather different if the sampling strategy was modified to address gaps within certain land uses, for example through equalising sampling intensities across all countries.

As mentioned previously, the choice of sample design is complex. Although the stratified random design performs better over all indicators, it might not perform as well for specific indicators. Table 4.6 illustrated the best scheme based on level of precision and smallest sample number. In the same manner, Table 4.24 shows the best scheme for each indicator, but based on 4000 sample points only. This shows, for example, that the stratified random design (RS) meets the criteria for all indicators in England and Wales (with the exception of zinc). However, in Scotland grid sampling is slightly better for SOC status and for copper in Northern Ireland.

Table 4.24 The best designs for each indicator based on scheme performance for 4000 samples only on a country basis.

	England	Scotland	Wales	Northern Ireland
SOC status	RS/Opt/Gr/RC	Gr RS	RS/Opt/Gr/RC	RS/Op/Gr
SOC change	RS RC	RS/RC	RS/RC	RS/RC
pH	RS/Opt/Gr/RC	RS/Opt/Gr/RC	RS/Opt/Gr/RC	RS/Opt/Gr/RC
Cu	RS/Op/Gr	RS/Opt/Gr/RC	RS/Gr	Gr Opt/RS
Zn	-	RS	-	-

Note: Designs in red/underline and on the same line are equal in performance and those below are the second best in performance.

4.6 Discussion on the critical assessment

The results from the critical assessment of the design-based and model-based options for sampling are reviewed in the following sections in relation to a unified approach to a UK soil monitoring scheme and for reporting at the country-level. The conclusions are based on the equal allocation of sample numbers across countries and land uses in proportion to area. The section on power analyses of the design-based approach reviews pros and cons of altering the sample allocation to achieve better results for individual indicators, land uses and countries.

4.6.1 Assessment of unified UK Scheme

It is clear that a decision on the sampling scheme cannot be made by a simple rule from the statistical results without weighing other considerations as identified above. There are several indicators with contrasting behaviour to consider, while the proposed soil monitoring scheme is expected to deal with many issues: identifying soils at risk, estimating change by land use, monitoring effects of climate change and so on. Flexibility of the design is therefore essential. It is important however not to attempt to "tweak" the design to meet many contrasting criteria, as the contrasting results for different indicators in our results indicate.

Given these facts, a sampling scheme that is simple, flexible and that gives good spatial coverage is most appropriate. A design-based sampling scheme based on spatial stratification has been seen to give good results for most indicators and, as noted at the end of section 4.2.3, does allow for the possibility of model-based analysis where required for answering a particular question (such as delineating affected soils). An alternative would be a grid-based scheme, which ensures good coverage. However, this does not allow for design-based inference, and so is somewhat less flexible than the design-based alternative, and in general would require more samples than a design-based scheme to achieve similar quality measures.

Analysis of the model-based schemes was based on full geostatistical estimation, which exploits spatial correlation (when samples from sites close together are more similar than samples taken from sites further apart). The weak spatial correlation seen for change in SOC may explain why the model-based schemes performed less well. It is possible to analyse samples from model-based schemes with design-based statistical methods, although the estimated errors could be large. One advantage of this approach would be the opportunity to modify existing soil surveys or monitoring schemes that were originally set up with sampling from a systematic grid. This would have a scientific and practical advantage of building on pre-existing data of not only specific UKSIC soil indicators, but also factors such as site characterisations, past land use and so on.

The ultimate choice of sample strategy for a UK soil monitoring network is complex. No one scheme is suitable for all countries and for all indicators. It is important that the pros and cons of each scheme are considered carefully before a final decision on the sampling strategy is made. A summary of the outcomes for each country is provided to aid the decision-making process, based on a UK sampling intensity of 4000 (Table 4.24).

The lack of appropriate spatial and temporal data on individual indicators limits the design process. A reasonable purpose of the monitoring scheme may be to obtain the relevant information, which could be built into a design option. Where no data are currently available for indicators, a reasonably simple design giving adequate spatial coverage (through stratification or use of an approximate grid) should provide sufficient baseline information about status. Adaptation of the sampling design may be appropriate as this information becomes available, while the total sampling intensity needed to achieve the required precision will vary by indicator. Country-level costs could be reduced a little if the laboratory analyses reflected the required sample number for each indicator.

4.6.2 Assessment in each country

England. All four design options give an achievable precision for status of SOC and pH, in all reporting classes, based on a design with 2015 samples. For copper, cluster sampling does not meet the precision for bog, but the remaining designs work well for all reporting classes. No design was reliable for zinc. Only the stratified random design meets the precision for SOC change in all classes, except coniferous woodland.

The current headline indicator of SOM for SFFS is based on a grid sampling design using reporting units comparable to the LCM strata. Reporting by NLUD would require re-allocation of ley grassland location into the cropped land category or the conversion of the SFFS to NLUD classes. Continued reporting on SOM for the SFFS would require either (i) a grid-based design, with inclusion of sufficient NSI sampling locations in a UK network to report on SOC status with possible augmentation to achieve the required precision in SOC change, (ii) transitioning to a stratified random scheme for both status and change, (iii) both designs in parallel or (iv) utilising stratification within a grid-based approach to improve estimates for the land uses of interest.

Northern Ireland. All but the clustered design achieve precision for SOC status with 346 samples. All design options were suitable for pH, and the grid sampling worked best for copper (again results are poor for zinc). Stratified random and cluster sampling were the most reliable for determining change in SOC, since the others did not perform as well for improved grassland. No design achieved precision for SOC change in unimproved grassland and built up areas. Designs may be improved by increasing sampling intensity in individual reporting units.

In Northern Ireland, grassland dominates land cover (there is little arable and forestry – about 6 per cent each), where soil monitoring has traditionally sampled at depths of 7.5 cm and/or A-horizon (including arable and intensive grassland soils). Moving to 0-15 cm would make direct comparison with previous surveys difficult. A grid design could sub-sample from the existing 5K sample locations to meet the sample requirement for the national scheme using the nearest match to the site to allow comparison with previous Northern Ireland surveys.

Scotland. All design options achieve the precisions for pH and copper. For zinc at 1220 samples, results are better than for other countries but still poor. As for England and Northern Ireland, a stratified random or cluster design was the most reliable for determining change in SOC. Grid sampling was the best for SOC status, though results were poor for broad-leaved woodland. Again, reallocation of samples between reporting units may improve the designs.

Wales. All four design options give an achievable precision for status of SOC and pH in all reporting classes with 419 samples. For copper, the stratified random and grid design was best. No design was reliable for zinc or for SOC change, although stratified random and cluster sampling did achieve the required precision for SOC change in dwarf-shrub heath and improved grassland.

4.6.3 Power analyses of design-based options

Statistical power analyses illustrated the likely sampling intensity required in each country to report by the different land uses, with the assessment of change in SOC requiring a much greater sampling intensity than other soil indicators. Increasing sampling intensity could improve the achievement of precision, a measure that could be addressed by reducing and/or amalgamating reporting classes within country, or by reallocating samples from one country to another. If all indicators considered in this analysis are of equal importance, the decision support matrix suggests that the stratified random design for 4000 points performs best overall. However, this scheme does not score well at determining SOC status in Scotland. For this indicator the systematic grid would be better under the current constraints. However, changes in the allocation of samples to land classes may improve the statistics for Scotland under a stratified random design.

The following allocations of sampling effort are recommended for different purposes:

- For reporting UK statistics: allocation in proportion to the area of each land use in each country.
- For reporting statistics at country-level: an equal number of samples in each country allocated to land use within countries in proportion to area.
- For reporting statistics within land classes within countries: an equal number of samples allocated to each land use in each country.

As the allocation that is optimal for one purpose is sub-optimal for others, we recommend that UKSIC prioritise requirements for each country since actual sampling intensity by country will be dependant on finalising, for each country, the land uses of interest, requirements for baseline information and supplementary reporting, and in particular the tolerance levels required for assessing status and/or change for essential indicators. From this, the necessary choice for sample allocation will become apparent.

4.6.4 Performance of canary indicators

None of the schemes that we assessed in this study will adequately assess both status and change in soil organic carbon for all land uses at a country level, but it should be borne in mind that the objective of this assessment was to look for general differences between scheme options. This is why in all cases of design-based and model-based options, the allocation of sample effort to countries was proportional to area; but this is not optimal for all objectives, as illustrated by the power analyses of design-based schemes. There is scope to achieve specific objectives for each country by reallocation of the total sample effort, as illustrated in Tables 4.8-4.10 for stratified random sampling. Although the value of stratification has been demonstrated in simulation modelling (c.f. Saby and Arrouays, 2004; Peltoniemi *et al*., 2007) as far as we are aware, this had not been demonstrated using actual field data until now. The assessment of the design options brought to light an intriguing and important result regarding the assessment of both status and change in SOC, in that it is clear that sampling schemes appropriate for assessing status are not necessarily suited to estimating change. This divergence has significant implications for any monitoring scheme aimed at assessing change in soil indicators in the UK and beyond, though perhaps especially for change in SOC.

Until more data are forthcoming, we do not know whether this phenomenon will be demonstrated in other indicators. The pattern of variation (status) in most indicators is determined by various environmental factors, and change may be related to status or it may not. Consider metals in soil, for example. Their variation at national scale is largely determined by geology, but change may depend on pollution, leaching and so on, and so the spatial variation of change need not look like the spatial variation of status. Therefore, a sampling scheme that is good for resolving a pattern of variation in metal driven by geology is therefore not necessarily suitable for resolving a pattern of variation in change driven by other processes.

This raises the question of how important assessing change versus status is. If the Defra SFFS SOM indicator is of the highest significance, then a stratified random scheme would be most appropriate, with reallocation of land classes within Scotland, after finalisation of the required tolerances for action levels in individual land uses. This identifies the need to reflect what should be the real canaries for a UK soil monitoring scheme. Clearly there are sufficient uncertainties over some of our initial canaries to warrant a “down-grading” of their status in the decision-making process, for example all designs are generally unreliable for zinc since zinc concentrations showed extremely high levels of variability across all reporting units.

Workshop Box 16: Status and change

The assessment of the scheme options brought to light an intriguing and important result regarding the assessment of both status and change in SOC. Given the constraints required, change in SOC could only be assessed accurately from a stratified random scheme (with 4000 samples) while SOC status could be reliably assessed from a grid-based scheme (with 1000 to 4000 samples). Although the value of stratification has been demonstrated in simulation modelling (for example see Saby and Arrouays, 2004; Peltoniemi *et al*., 2007) as far as we are aware, this had not been demonstrated using “real” data, until now.

This raised the question as to whether both status and change were required from indicators. The consensus was that, especially for carbon, both were essential requirements. Therefore, further effort is required to establish the most appropriate stratification for relevant indicators at the country-level, once appropriate tolerance levels are established.

4.6.5 Influence of levels of tolerance on assessment

The scoring in the decision matrix was based on the performance assessment of the schemes, which is closely related to the tolerance levels used. The tolerance levels used in this project were primarily based on the expert judgement of the project team. The values were deemed appropriate to test the different design options, and were not selected as the most suitable for UKSIC purposes. As shown by the example for bulk density (Section 4.2.2), the available spatial information could be used to determine minimum detectable differences at 95 per cent confidence levels, which could then be used to inform on appropriate tolerance levels for individual indicators with respect to different land uses and countries. There is a recognised scarcity of temporal data for indicators at the large scale. Tolerances for change indicators may be informed from long-term site data and from data forthcoming from the NSIS resurvey, CS2007 and the Environment Agency road-testing project, in the first instance.

It is important that UKSIC establish what levels of tolerance would be acceptable to match its requirements. For example, if the monitoring information has a regulatory consequence then UKSIC may require relatively narrow acceptable tolerance intervals, for example concentrations of metals in agricultural soils. The bulk density example illustrates that currently spatial data can inform this process by establishing minimum detectable differences at 95 per cent confidence.

Changing tolerance levels may also influence the outcome of the decision-making process. However, given our results, changing the tolerances would be unlikely to alter the fact that the stratified random design generally performed better than a grid design. The capacity to alter the sampling intensities to reflect the required tolerances may however result in all design options, including grid-based, performing better than currently demonstrated for some indicators.

4.6.6 Influence of reporting classes on assessment

It should also be considered that the stratified random design has been evaluated for reporting on land cover classes only. There has been no assessment for reporting by atmospheric pollution or climate change scenarios. A sampling scheme that is designed to ensure sufficient representation of a complete set of particular reporting classes might prove inefficient for reporting on other effects, or on a different set of classes should these prove of interest in the future. A stratified random sample aimed at giving good spatial coverage (design-based), or a grid sample (model-based) might be preferred if we want a scheme with greater flexibility. Other options would be:

- Further amalgamation of the NLUD Land Cover classes may be used to improve the reporting of land uses within countries, particularly where some land uses are sparse or under-represented. It is likely that this would reduce the variance, though this should be established for each country if a reduced set of reporting classes is agreed. For example, reporting units could be reduced from 16 to five:
    - Cropped land (NLUD Order)
    - Improved grassland (NLUD group)
    - Unimproved grassland (NLUD group)
    - Woodland (NLUD Order)
    - Heathland (NLDU Order)
- Additional land use reporting classes whose location can be spatially identified beforehand. Examples of this are some of the agricultural classes, which should be identifiable with a high degree of accuracy using IACS datasets within a GIS setting. With a not inconsiderable amount of effort these classes could be built into the stratification scheme, and hence

allowed for in drawing the locations to be visited. If information about these additional reporting classes is required, we recommend they be included in the sampling strata after the necessary additional GIS work. An alternative approach is to use aerial photographs to screen randomly selected points within the design strata; however, this would have the disadvantage of still needing to estimate the extent of each such reporting class in each design class, and the number of trial-and-error points to be drawn before reaching all targets may be large.

- Reporting classes that can only be identified in the field. Classes based on the clay content of soils required for reporting carbon fall into this category. Good sample sizes for such classes cannot be guaranteed *a priori*. These could be accommodated in the design through knowledge of their relative frequencies in each design stratum and by drawing additional sampling locations to make reasonable coverage of these classes likely. A more exact method of dealing with this issue would be some form of quota sampling, in which locations are drawn at random within strata, visited, and a probabilistic rejection rule applied to determine whether or not to include the location in the sample. In either case, obtaining reasonable sample sizes from rare classes would require a considerable amount of effort over and above that required for getting adequate sample sizes for the strata known *a priori*.

Where reporting classes already exist for indicators, one option would be to adapt to the reporting classes adopted for the UK network, for example translate the SFFS headline indicator for SOC to land cover classes

4.6.7 Spatial stratification

Inclusion of Land Cover class in the design-based sampling can significantly improve the estimation of means for individual classes. It does, however, restrict the future flexibility of a network to reporting by these classes as they appear from the design stratification. There is the distinction between the land cover class with a certain name and the set of visited locations that would be allocated to this name by a field surveyor. For example, grassland pockets will be found in land cover classes such as woodland and heathland, and so may be selected for sampling from the woodland or heathland land cover classes.

The question is: to which reporting class should such samples be allocated? The argument in favour of allocating for primary reporting purposes to the land cover class by design is strong, as we then know the spatial domain to which the sample refers. However, this would not preclude some secondary analyses for misclassifications that occur frequently. An alternative approach would be to consider a multivariate statistical stratification of the UK environment to support stratified random sampling, for example the Environmental Stratification of Europe (Metzger *et al*., 2005) with the land uses determined from sampling in the field, which is similar in approach to using the ITE Land Classification as the sampling framework for the Countryside Survey. However the effectiveness for soil monitoring would need to be fully established.

We would recommend that the strata used in the final design are the required policy reporting classes or subdivisions of them for two reasons. Firstly, this allows the sample size in each reporting class to be controlled so as to ensure that it is likely that the quality criteria will be met. Secondly, if the strata used in the design cannot be combined to form the reporting classes, there is a risk that few or even no samples may be taken from some combinations of stratum and reporting class that exist in the population. In this latter situation it will not be possible to obtain unbiased estimates of the mean of the reporting class. This approach will reduce future flexibility, that is if reporting requirements change, but it would be the most appropriate approach in ensuring that known policy requirements could be met from a UK soil monitoring network.

End-users, including UKSIC, need to carefully consider whether they would be content with retaining the NLUD land cover reporting classes over several monitoring intervals. If not, then there needs to be further consideration of what could be retained over several decades, and therefore is suitable for the basis of stratification, or whether (i) effort is required to establish a statistical stratification approach or (ii) a grid-based option would be more useful as it provides optimal flexibility although there are constraints to reporting on specific indicators, in particular SOC change.

4.7 Way forward – prior to the Workshop

A way forward to a preferred design was to focus on the priorities within each country. At the stakeholder workshop, decisions were required on the following:

- Establish priorities for allocating sampling effort by defining level of requirements for statistics, such as country and land use, country and then UK, as outlined above. This will influence the levels of precision that can be achieved for each indicator within each country. In particular, samples could be reallocated to Northern Ireland and Wales.
- Establish the relative importance of each reporting unit (with land cover classes as reporting units) in each country.
    - Specifically, could some be amalgamated, removed or re-allocated to improve the statistics in other reporting units. This will influence sampling effort and potentially address precision.
- Establish the priority of indicators and canary indicators for each country for each function.
    - At present there are several indicators for certain functions. Reduction of these to the essential indicators or action levels for each function will increase the capacity of any design to deliver required precision.
    - Zinc concentrations are highly variable across all reporting units within each country. Zinc as a canary indicator must therefore be reviewed otherwise no design is suitable for any country.
- Establish the tolerance levels (precision) for each indicator for each land use for the individual soil functions, in each country.
    - For example, SOC change has proven difficult to establish at precision of +/- 20 per cent, particularly in soils of low SOC content, for all designs in all countries. It may be more appropriate to set precision levels for individual SOC classes or specific land uses which reflect potential and/or unacceptable levels of change in these classes for UKSIC purposes. This may improve the performance of the design options.
- Establish indicators to assess the threats of climate change or atmospheric deposition within a UK soil monitoring network.
- Establish the essential supplementary reporting requirements for each country and determine whether these should/can be included in the design.

For example, organic and mineral soils in Scotland or texture class for England and Wales to report on food and fibre production.

- Establish whether a single unified database system would be adequate to meet UKSIC requirements. Given the current capacity to access databases on-line, it would be more cost effective and scientifically rigorous to maintain the soils data as a single unified UK database with access provided on-line as required or on request.
- Establish whether there will be a complete UK sample archive or one archive per country.
- Establish whether the UK network should provide baseline information required to advance the deployment of indicators where data are currently insufficient.
    - There are several surveys and monitoring schemes within the UK that could provide supporting information, particularly with current activities across Great Britain and within Scotland.
    - Consideration should be given to an agreed set of soil properties and processes that underpin soil functions to address baseline requirements, introduce a degree of future-proofing against as yet unknown threats, and report the state of soil in total.

Workshop Box 17: Generic outcomes
The results of the design project to the end of this Section, including issues requiring clarification, were discussed at the UKSIC workshop held at CEH Lancaster (6-7 November 2007). The specific outcomes have been summarised in the relevant sections in this report.

Generic outcomes: The workshop proved to be a critical way forward in the decision-making process and future projects of a similar nature should consider having a workshop much earlier in the process to address issues arising, or a series of smaller stakeholder meetings or workshops throughout the process.

4.8 Conclusions from the critical assessment

The critical assessment brought together all the information gained from the designing options phase into a single decision-making framework, to support a structured comparison assessing the relative performance of the model-based and design-based sampling options across all indicators and reporting units at a range of sampling intensities. In addition, outline costs for completing a monitoring scheme based on each sampling option were included in the assessment.

The results further confirmed that, in most instances, the design-based stratified random sampling would yield the most robust statistical information for the greatest number of indicators by land use within each country, particularly if assessing change in SOC is a high priority. Soil pH status and change, however, can be assessed effectively using either model-based or design-based options in all countries. There are unresolved issues over the effective monitoring zinc.

The costings were calculated from the initial sample allocation from the designing phase, that is, allocation to countries and land classes in proportion to area, with a minimum sample size in each country/land-class combination. This gave maximum outline costs of £2,854,943 for a random stratified UK scheme with 4000 samples and

£3,070,896 for a grid sampling UK scheme again with 4000 samples, illustrating that there are relatively minor differences in the overall costs of the different options.

The results for the power analyses indicated that sample allocations will require further optimising based on a final overall reporting priority for the monitoring scheme. However, allocation to report statistics within land classes within countries (that is, an equal number of samples allocated to each land class in each country) gave comparable results at both the country and land use by country level and are therefore a candidate allocation for country-level reporting. The cost implications are outlined in the implementation section.

Several technical issues relating to the priorities of a UK soil monitoring scheme, and therefore the requirements for different sampling options, were highlighted during this task. These were outlined and discussed at the stakeholder workshop. Some issues remain outstanding for further consideration of UKSIC. The outcomes from the workshop, including outstanding issues, are detailed in the workshop summary boxes that were subsequently added to the relevant sections throughout this report.

5 Implementation

5.1 Introduction

The objective of this task was to produce a process map, a set of standard operating procedures and revised outline costs to provide guidance to whichever party undertakes the monitoring of soils using the preferred design and to establish compatible procedures across all countries. The framework is not meant to be exhaustive but rather it is indicative of the likely requirements and considerations involved in the implementation of the chosen monitoring scheme. It is noteworthy that both the process map and standard operating procedures are not influenced greatly by which design option is selected.

5.2 Process Maps

A process map has been constructed to capture the overall sequence of processes, responsibilities and outputs required for the implementation of the UK soil monitoring scheme. The map has been produced using MS Visio which allows interactive connections between the different pages of the map via the ‘off page references’. It is intended that the process map should be ‘self explanatory’ with reference to the key to symbols included in the summary. The map is presented as a series of images in Appendix F with a summary in Figure 5.1.

The map summary (Figure 5.1) gives a simple linear progression of the main processes within the map and their links to individual map pages, each of which provides a breakdown of the details of each process. The process map does not include the detailed series of instructions for each operation, as these are incorporated in the SOPs (Section 5.3).

The process map makes the fundamental assumption that a new monitoring scheme will be set up with the sampling design as recommended by this project. Furthermore it is assumed that the contractor undertaking the monitoring will either be provided with the sample point locations derived from the design, or will be given sufficient information to specify the sample point locations.

Secondarily the following assumptions are also made:

- There will be a Project Manager with overall responsibility for delivery of the project to the funders (including budget and timing) (Map P2).
- The Project Manager will delegate responsibility to Task Leaders for:
    - Quality Assurance and Quality Control (Map P2).
    - Field preparation and sampling (including site access permissions; Maps P3 & P4).
    - Sample preparation and laboratory analysis (Map P5).
    - Information and sample archive management (Map P6).

The Project Manager and the four task leaders will form an internal project management group. This group will also be responsible for the producing the final report.

- There will be an external steering group appointed by the funders. Appointments to this group will be made in consultation with the Project Manager and Task Leaders and will include the Project Manager, a representative of each funding body and one or two external experts to provide impartial advice.
- There will be a statistical advisor drawn from the project team involved in the design project. This person will provide advice to minimise the effects on the monitoring scheme design of potential problems such as refused access to sample sites etc. The statistical advisor will be included in the internal project management group and may be included as one of the 'experts' on the external steering group.
- The soil monitoring scheme will be operated according to the Defra Joint Code of Practice for Research (JcoPR). The Task Leader responsible for Quality Assurance/Quality Control (QA/QC) will oversee the application of JCoPR throughout the implementation of the monitoring scheme.

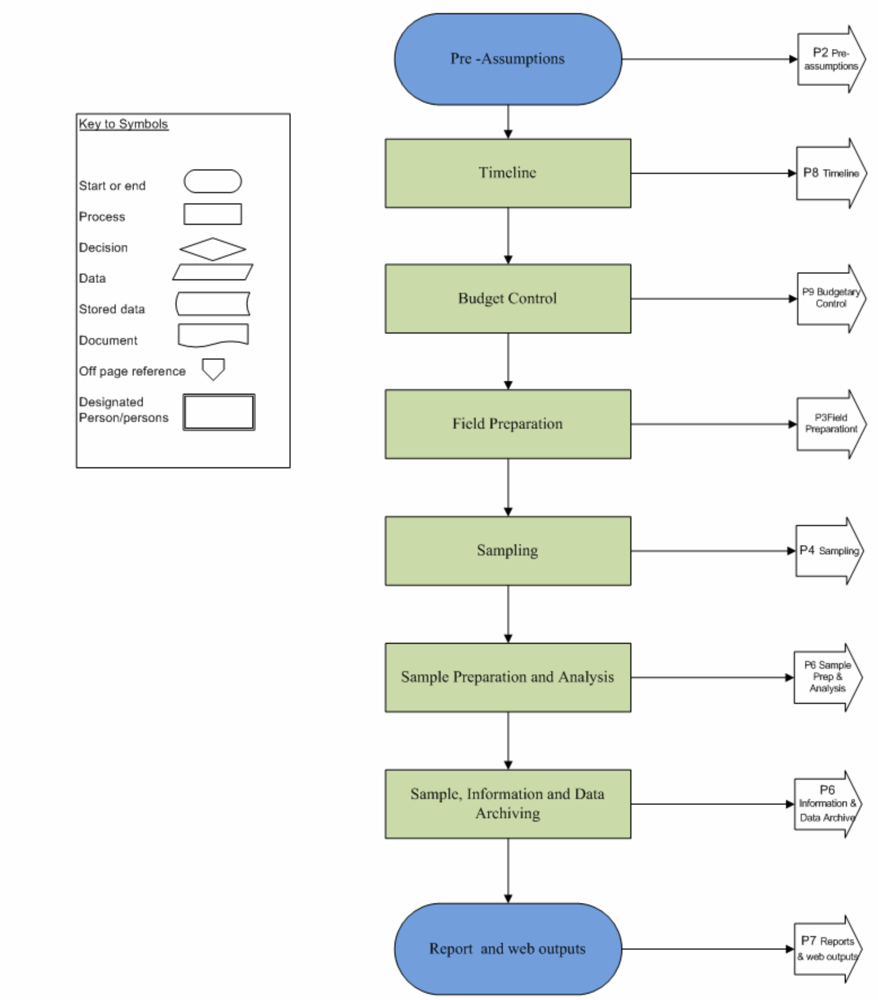


Figure 5.1 Summary of the process map for soil monitoring. This illustrates the simple linear progression of the main processes within the map and their links to individual map pages each of which provide a breakdown of the details of each process.

5.2.1 Notes to accompany individual maps (Appendix F)

1. **Summary (Map P1):** This map details the linear progression of the main features of the process map.
2. **Pre-assumptions (Map P2):** This map describes the project management structure and the responsibilities of the project manager and task leaders.
3. **Field Preparation (Map P3)**: This map covers the tasks required to set up the programme of field sampling including:

Logistics. This includes:

- Recruitment and training of temporary field staff. The importance of this task should not be underestimated given the lack of trained soil scientists available in the UK.
- Health and Safety tasks including writing risk assessments and safe systems of work and staff training.
- Acquisition of field equipment including any personal protective equipment to meet Health and Safety requirements. This task requires sufficient time to be allowed for large purchases (such as sample bags), manufacture and testing of any equipment specifically designed and built for the monitoring scheme (such as soil cores, adaptation of digital data capture equipment) and the preparation of field packs for sampling teams.
- Estimating the travel and subsistence budget based on the planning of the field season

QA and QC documents. This involves translating the JCoPR into practical guidelines and instructions for individual tasks, plus setting up the appropriate systems and checks within each task and SOP.

Contingencies. Contingency planning to cover unforeseen circumstances in relation to project spend and timeline. A risk log should also be developed and regularly reviewed.

4. **Sampling (Map P4): T**his map links directly to SOPs UKSMS001:2008 (Establishment of a Sampling Point); UKSMS002:2008 (Site and Profile Description) and UKSMS003:2008 (Sample Collection and Storage). It allows for the contingency that permission may be refused when the sampling team turn up on site, and for lack of appropriate soil at the site.

5. **Sample Preparation and Analysis (Map P5):** This map covers all tasks associated with the receipt, preparation and analysis of samples as covered by the recommended procedures in Section 5.3.
6. **Sample, Information & Data Archiving (Map P6):** This map covers tasks associated with archiving samples and data from monitoring and maps and links to SOPs UKSMS004:2008 (Archiving of samples) and UKSMS005:2008 (Data management and archiving).
7. **Report and Web outputs (Map P7):** The map assumes both hard copy and web-based outputs will be produced by the project and that the data will be accessible via a project website. A project website will be developed at the outset of the project.

8. **Timeline (Map P8):** Allows a check against proposed timeline for project (see Gannt chart). This timeline will include a contingency for tasks taking longer than estimated due, for example, to poor weather conditions during fieldwork. The timeline will be reviewed monthly with Task Leaders. Where it is clear that a task will overrun the contingency time, this should trigger a review with the external steering group as additional resources may be required. The contingency for both project timeline and budget are specified in the Field Preparation stage (Map P3) as it is assumed that the major area of risk to the project is likely to be completion of the field sampling task. This task is also one of the most expensive and is subject to uncontrolled factors such as poor weather and difficulties with site accessibility. Note: the Gannt chart provides an estimated timeline and the specified years are for illustration only.
9. **Budget control (Map P9):** Allows for a regular check on the project spend against budget. As for the timeline, a contingency will be allowed to cover unforeseen expenditures due, for example to increases in prices of consumables, overrun of the field sampling task and so on. The budget will be reviewed monthly with Task Leaders (Map P9) and expenditure beyond the contingency will be reviewed with the external steering group.

5.3 Standard Operating Procedures

The objectives were to translate the process map into a series of Standard Operating Procedures (SOP) for each sub-process. Each SOP describes the procedure for carrying out a particular stage in the monitoring process in a precise and consistent way. A format for all the SOPs has been chosen that reflects that used in pre-existing ISO standard analytical procedures.

The field practices, sampling strategies, sample preparation and analysis procedures and storage practices employed by key organisations involved in previous soil monitoring projects have been collated and assessed in order to make recommendations for any future monitoring exercise and to draw together a set of SOPs for each step.

5.3.1 Format for standard operating procedures

It is proposed that the layout, format and content of the BS ISO standards is adopted for all SOPs comprising the procedures for UK soil monitoring. These have a numerical year of drafting combined identifier, a version control table to identify amendments and the following contents as appropriate:

Title
1. Scope
2. Normative references
3. Principle
4. Reagents
5. Apparatus
6. Laboratory sample
7. Procedure
8. Repeatability
9. Test Report

10. Results of any inter-laboratory trials
11. Bibliography

5.3.2 Review and selection of standard operating procedures

This section compares the different candidate procedures that are current practice for key organisations involved in soil survey and monitoring activities, and recommends a preferred procedure for a future UK soil monitoring exercise.

Field procedures

Decisions about sampling design, that is, the spatial and temporal frequency and pattern of sampling, are yet to be taken and rest upon determination of the exact objectives of the future sampling exercise. This section therefore deals with the procedures to be undertaken once a set of sampling points has been determined. Previous practices for key monitoring programmes are summarised in Table 5.1 and recommendations then made for the UK monitoring exercise.

Sample point selection

A standard operating procedure for the translation of a geo-referenced site on paper into a point with underlying soil in the real landscape that can be sampled, UKSMS 001:2008 Establishment of a Sampling Point, (see Appendix G) has been designed and drafted. Decisions may be taken locally by national governments or departments to collect further information or samples over and above this core programme.

The procedure allows for situations where the original site is inaccessible or has no soil, and the recording of this on the Standard Field Recording Proforma. If, after undertaking the procedure, no suitable site can be located, the site is excluded from the monitoring exercise and a note explaining the exclusion made on the field proforma.

Description of the sampling site and soil

Previous sampling programmes have used their own distinctive description protocol that has reflected their individual objectives. These are not reviewed here. A standard operating procedure has been drafted (UKSMS 002:2008 Site and Soil Profile Description, Appendix G) that reflects the conclusions of the workshop groups and project team. It is recommended that a soil pit is dug, described and samples taken for a) bulk density measurement, and b) possible future soil horizon chemical characterisation.

Table 5.1 Field procedures

Survey	Reference	Description
NSI England and Wales	Source: Soil Survey of England and Wales (Unpublished) Sampling and Recording for the National Soil Inventory	Sites on a 5 km grid displaced 1 km north and east from the Ordnance Survey National Grid 00 and 05 km grid lines were visited using 1:25,000 maps to locate the sampling point. Where the point was inaccessible or there was no soil, a defined procedure was followed to find a substitute site. At each site, a soil pit was dug to 80 cm and augered to 120 cm and the site and soil described according to the Soil Survey Field Handbook (Hodgson, 1976) and recorded on a standard proforma. A bulked topsoil sample (0 - 15 cm excluding vegetation and litter) was collected with a screw auger from 4 m intervals within a 20 x 20 m square around the pit. For organic soils, this proved to provide insufficient sample and further sub-samples were collected from the same spatial intervals.
Countryside Survey	Source: CEH (2007) Countryside Survey 2007 WP 4 Soil Report Annex 1 Soil sampling protocol. Unpublished.	Fixed sampling sites of 1 km square located through GPS, photographs and OS grid coordinates. There are five fixed sampling plots in each 1 km square (X-plots), which are located as above with, in addition, a permanent marker in the soil nearby. Four cores of varying depth are taken from a specific location relative to the centre of each X-plot of the Countryside Survey sample squares. A number of tubes of varying lengths up to 15 cm and 4 or 5 cm diameter are used for collection and hammered vertically into the soil surface. Discretion is allowed regarding relocation of sampling points if roots, stones or other obstacles prevent sampling. Each core is uniquely identified and is used for different analyses and storage regimes therefore vary.
NSIS Scotland	Source: Soil Survey of Scotland (Unpublished) National Soil Inventory of Scotland (NSIS_1) 1978-88	NSIS sample locations on a 10 km grid aligned to Ordnance Survey National Grid 00 grid lines were plotted from 1:50 000 scale Ordnance Survey maps on to air photos that have an approximate scale of 1:25 000 using a 'sketch master' that allows the superimposition of both map and photo images. The location of the grid intersect was marked with a small dot (approximately 0.5 mm diameter) on the photo. The national grid reference was clearly marked on the photograph. Once at the site a soil pit was dug and the soil and site described and relevant samples taken generally from a 10cm band in the middle of each horizon. Where the site lands on an area with no soil cover, a site within 100m from the grid intersect point was located, firstly to the north and then to the east, south or west.
Northern. Ireland NSI	Source: Higgins, A. (2003) Soil sampling to 7.5 cm and to horizon depth. AFBI Agricultural and Environmental Science, Unpublished.	Sites on a 5 km grid using the Irish Grid were visited using 1:10,000 maps and orthophotos to locate the sampling point. Where the point was inaccessible or there was no soil, a defined procedure was followed to find a substitute site. Soil samples to 7.5 cm depth are taken at 2 m intervals along a 71 m transect chosen to be representative of the field and bulked to give a single representative soil sample for that site. A single topsoil sample (1 kg) is also taken from the entire depth of the A horizon exposed in a pit dug at the midpoint of the 71 m transect.
BioSoil	Sources: (1) Vanguelova, E (2005) BioSoil - site selection protocol. Unpublished. (2) Forest Research (2006) Site selection for BioSoil soil and biodiversity surveys. Unpublished Standard Operation Procedure	A 500 x 500m square divided into 25 100x100m grid squares is laid out around the sampling point and each 100 x 100 m square assessed according to an identified sequence in order to find the nearest cell with >50% woodland. A 25.24 m radius circle is delineated on the map (biodiversity plot) and a soil pit location identified within this circle. The positioning of the circle can be varied in the field in response to forest conditions but its final position is permanently marked with a marker driven into the ground. The soils of the site are described and a profile, representative of the dominant soil described according to FAO guidelines (FAO 1990) and the soil classified according to the World Reference Base of Soil Resources (FAO *et al.* 1998). Soil horizons are sampled and analysed to confirm classification. The soil pit must be located more than 20 m in from any forest edge. Surface organic horizons are sampled using a 25 * 25 cm sampling frame and then mineral layers (mandatory or optional fixed depths of 0-10, 10 - 20, 20 - 40 and 40 - 80 cm depending on the status of the site) are taken. Bulk density samples are taken at 0 - 10 cm.

Sample Collection

A new standard operating procedure has been drafted (UKSMS 003:2008 Sample Collection and Storage, Appendix G). This requires the collection of three types of sample at each site.

A bulked composite, topsoil sample will be collected by gauge auger at regular intervals over a 20 x 20 m area from the 0-15 cm soil layer (vegetation and L layer removed prior to depth calculation). A total weight of 1 - 2 kg soil is to be collected from topsoils with less than approximately five per cent organic carbon. A greater volume of soil should be collected from topsoils with higher organic carbon content because of their much lower bulk density. This will normally also equate with a greater weight of soil because of the much higher water content. The bulked sample will be placed in a double plastic bag with a waterproof label marked with the site number and grid reference inserted between the inner and outer bags.

Bulk density samples will be collected from soils with mineral subsoil at two depths centred on 5 and 20 cm from the soil surface (excluding vegetation and litter). Triplicate core samples will be taken using a core sampler from alongside the soil pit by cutting a step from a side of the soil pit that has not been trodden on or disturbed during excavation of the original pit. For *peat soils*, that is, soils with one or more organic subsoil horizon, triplicate bulk density core samples of known volume (minimum 500 cm^3) will be taken at depths of 10, 25, 50 and 75 cm from the soil surface.

In all instances, the triplicate cores for each depth will be bulked for a single measurement of bulk density. Each bulked sample will be placed in a plastic bag with a waterproof label identified with the site number, grid reference and depth placed between the inner and outer bags.

Horizon samples will be collected from the soil pit for each horizon to the base of the lowest B horizon or 75 cm, whichever is the deeper. The organic layer at the soil surface may consist of the following layers: litter (L), fermentation (F) and/or humus (H). The litter layer is to be discarded and sampling commenced from the F and H layers where present, then subsequent mineral horizons. A maximum of four horizons should be sampled due to cost of processing samples in the laboratory. The ISO 11464 method (Soil quality – Pre-treatment of samples for physico-chemical analysis) recommends at least 500 g of fresh soil for each sample.

Field to laboratory sample treatment

The treatment of soil samples between the field and laboratory is relatively generic and a detailed review of previous practices was not carried out. Procedure UKSMS 003:2008 Sample Collection and Storage (see Appendix G) has been drafted in light of the conclusions of the workshop and discussions within the project team, and is recommended for adoption in any future UK soil monitoring exercise.

Analytical procedures

Sample preparation

Previous candidate practices are reviewed in Table 5.2 for the preparation of the bulked composite topsoil samples. The aggregated triplicate bulk density samples need no preparation and are not therefore considered at this stage.

Table 5.2 Sample preparation

Survey	Reference	Description
NSI England and Wales	Source: McGrath, S.P. and Loveland, P.J. (1992) The Soil Geochemical Atlas of England and Wales. Blackie Academic and Professional, London.	After collection, samples were transferred to the laboratory and air-dried at room temperature. Half of each air-dried sample was milled in a mild-steel roller mill to pass a 2 mm sieve. All chemical analyses apart from total elemental concentrations were measured on this material without further crushing. The other half of the sample was kept in an unground state as an untouched sample that could be resorted to in cases of contamination at any stage. For total element analyses a 25 g sub-sample of the <2 mm soil was obtained by coning-and-quartering and ground to <150 µm in an all-agate planetary ball mill.
Countryside Survey	CEH (2007) Countryside Survey 2007 WP 4 Soil Report Annex 2 Soil laboratory protocol. Unpublished.Surveys)	Soil is broken up and homogenised. A 10 g sub-sample is taken for pH (avoiding stones and roots). Sample is then dried at 25°C with crushing during the process (if necessary). When soils have dried sufficiently they are sieved through a 2 mm stainless steel mesh using a wooden paddle. A sub-sample is taken with further sub-samples ground (<0.5 mm) or agate-ball milled for subsequent analyses.
NSIS Scotland	Source: Macaulay Institute for Soil Research (1971) Laboratory Notes on Methods of Soil Analysis. Unpublished Handbook.	The field sample was spread out and dried in a warm-air room (about 30°C). The sample was then repeatedly rolled, crushed gently and shaken on a 2 mm sieve to derive a <2 mm soil fraction. Coning and quartering was used to derive a 2-3 g representative sub-sample which was subsequently finely-ground sample in an agate ball mill to approximately 100 mesh (150 µm).
Northern. Ireland NSI	Source: MAFF (1986) The analysis of agricultural materials, MAFF/ADAS Reference Book 427. Method 2 Preparation of samples of soil.	Soil samples were transferred to a tray. Stones were removed by hand and the sample dried in an oven not exceeding 30°C for a minimum of 40 hours and until no sign of moisture remains. The dried soil was transferred to grinding canisters containing steel pestles that process the soil to derive a <2 mm soil fraction by sieving through a 2 mm sieve.
BioSoil	Source: Forest Research (2006) Preparation and storage of soil samples for analysis for the BioSoil project. Unpublished Standard Operation Procedure	After removal of living material (such as mosses, roots) and objects >2 cm, collected samples should be air-dried or dried at a temperature of 40°C. The sample is subsequently crushed or milled to size <2 mm.
Environment Agency (National Laboratory Service)	Source: Environment Agency (2008.) Classification, drying and preparation of soil, sediment and waste samples. Unpublished Work Instruction.	Sample is air-dried for 24 hours in a drying room where the temperature is not greater that 30°C. If the sample has dried into large, hard lumps (aggregates), it may be broken up using a pestle and mortar to allow it to pass through a 10 mm sieve. Sample is then processed through a ball mill and the <2 mm fraction retained.
BS ISO 11464:2006	Source: British Standards Institute.	The complete sample is air dried or dried in a ventilated drying oven not exceeding 40°C; to accelerate the drying process, breaking down the larger aggregates (>15 mm) during the process. Before crushing, which is necessary if soil samples have dried into large aggregates, extraneous matter should be removed from the dried sample. This process may be facilitated by the use of a 2 mm sieve. Care is taken to minimise the amount of fine material adhering to the extraneous matter removed. If a 2 mm sieve has not been used to facilitate removal of extraneous matter, then the dried sample is sieved through a 2 mm sieve. Any large dried particles remaining on the 2 mm sieve is crushed (using suitable apparatus) to smaller than 2 mm. The apparatus used is adjusted in such a way that complete crushing of particles larger than 2 mm before drying is minimised. For the preparation of the laboratory sample, the dried sample is divided, crushed and sieved (now <2 mm) into representative portions of 200 g to 300 g. The laboratory sample is split into representative portions until the required sizes of sample are obtained. Milling of the material between sub sampling stages may be necessary, to ensure homogeneity as the mass of the sub-sample is decreased.

All reported schemes are broadly similar. Macaulay, NSRI and NLS are the only schemes where a sub-sample of the original pre-treated soil is retained (although will have been air-dried first).

The ISO standard covers all eventualities except possibly leaf litter and living material and it is recommended that this procedure be adopted for any future UK soil monitoring programme. Each soil sample will need to be divided into archive sample(s) and test sample(s) and the specifics of this should be covered in the final SOP once the list of determinations and number of archives is finalised.

Soil pH (measurement units: none)

Candidate procedures are reviewed in Table 5.3

Table 5.3 Soil pH

Survey	Reference	Description
NSI England and Wales	Source: McGrath, S.P. and Loveland, P.J. (1992) The Soil Geochemical Atlas of England and Wales. Blackie Academic and Professional, London.	10 ml of air-dried, <2 mm soil was shaken for 15 minutes with 25 ml of water. The pH of the resulting slurry was then measured after the electrode had been inserted for 30 seconds.
Countryside Survey	Source:CEH (2007) Countryside Survey 2007 WP 4 Soil Report Annex 2 Soil laboratory protocol. Unpublished.	10 g of field-moist soil is stirred thoroughly with 25 ml of water and then left to stand for 30 minutes. The pH electrode is then inserted into the thoroughly stirred suspension for at least 30 seconds. A stable reading (reading changes by no more than 0.02 pH units in 5 seconds) is recorded. In addition, 10 g of air-dried, <2 mm soil is stirred thoroughly with 25 ml of water and then left to stand for 30 minutes. The pH electrode is then inserted into the thoroughly stirred suspension for at least 30 seconds. A stable reading (reading changes by no more than 0.02 pH units in 5 seconds) is recorded.
NSIS Scotland	Source: Macaulay Institute for Soil Research (1971) Laboratory Notes on Methods of Soil Analysis. Unpublished Handbook.	20 ml of air-dried, <2 mm soil is stirred thoroughly with 50 ml of water and is then left to stand for 2 hours. The pH of the resulting slurry is then measured.
Northern. Ireland NSI	Source: Agriculture Food and Environmental Science (2007) Determination of soil pH, extracted with water, using a Skalar SP10 robotic analyser. Unpublished Standard Operation Procedure.	Approximately 15 g of 2 mm soil was thoroughly shaken with 45 ml of distilled, CO_2 –free water and allowed to stand for at least 4 hours. The pH of the suspension was then recorded.
BioSoil	Source: Forest Research (2006). Lab Manual. Unpublished.	A representative sample (at least a volume of 5 ml) of the air-dried, <2 mm soil was taken and added to five time its volume of water. The suspension was shaken or mixed vigorously for 5 minutes and then left to stand for 2 hours. The suspension is shaken before measurement of the pH and the pH value is that recorded after stabilisation is reached.
Environment Agency (National Laboratory Service)	Source: Environment Agency (2007) Determination of pH and electrical conductivity in soil. Unpublished Work Instruction.	20 g of air-dried <2 mm soil is shaken for thirty minutes with 50 ml of water. The extract is then allowed to settle for 30 minutes. The liquid extract is then decanted into sample cups and the pH measured after stabilisation is reached.
BS ISO 10390:2005	Source: British Standards Institute	A representative sample (at least a volume of 5 ml) of the air-dried, <2 mm soil is taken and five times its volume of water added. The suspension is shaken or mixed for 60 minutes and then left to stand for at least 1 hour but not more than 3 hours. The suspension is shaken before measurement of the pH and the pH read after stabilisation is reached (reading changes by no more than 0.02 pH units in 5 seconds).

Every scheme is different but a 1:2.5 soil:water ratio is the most common suspension ratio, though it should be noted that using a mass of soil differs from use of soil by volume. CS includes measuring the pH of a field-moist soil but has shown that air-drying does not have a significant effect. Using the ISO standard would be reasonable but it is suggested that this be modified to make use of a 1:2.5 by volume extract. Defra report SP0515 (2003) compares soil properties from a range of data sources and show that differences in methodology result in statistically significant differences between data from different monitoring schemes. However, in terms of land management, it needs to be recognised that the differences between pH values of, for example, 6.3 and 6.6 are of no practical significance.

It is therefore recommended that 10 ml of air-dried, <2 mm soil is stirred thoroughly with 25 ml of water and then left to stand for 2 hours. A pH electrode is then inserted into the thoroughly stirred suspension for at least 30 seconds. The stable reading (reading changes by no more than 0.02 pH units in 5 seconds) is taken as the soil pH.

Organic carbon (measurements units: g/kg)

Candidate procedures are reviewed in Table 5.4. Dichromate digests use environmentally unfriendly and hazardous chemicals. The ENVASSO project (Jones, 2008) recommends the use of determining SOC content by the indirect determination of the dry combustion method (removal of carbonates prior to analysis) and it is recommended that this technique be adopted in future UK soil monitoring. To allow for historical comparisons, analysing a minimum of 10 per cent of existing soil samples by dry combustion to establish a conversion factor is recommended

Table 5.4 Soil organic carbon

Survey	Reference	Description
NSI England and Wales	Source: McGrath, S.P. and Loveland, P.J. (1992) The Soil Geochemical Atlas of England and Wales. Blackie Academic and Professional, London.	Organic carbon was measured either by loss-on-ignition (850°C) for soils estimated to contain more than about 20% organic carbon (Avery and Bascomb, 1982), or by dichromate digest with additional heating (Kalembasa and Jenkinson, 1973).
Countryside Survey	Source:CEH (2007) Countryside Survey 2007 WP 4 Soil Report Annex 2 Soil laboratory protocol. Unpublished.	Loss-on-ignition (in 1978 at 375°C and at 550°C and 375°C for CS2000 and CS2007 samples). Total soil carbon by CHN elemental analyser in CS2000 and CS2007 plus Walkley Black method (with no additional heating on a proportion of samples). Currently no allowance for carbonate, as a relatively small proportion of all samples, but may be retrospectively carried out.
NSIS Scotland	Source: Macaulay Institute for Soil Research (1971) Laboratory Notes on Methods of Soil Analysis. Unpublished Handbook.	Total carbon was measured by CHN analyser after the sample was crushed in an agate ball mill to <150 µm. Silicon carbide milling was introduced recently. The sample was pre-treated with acid to remove any carbonates prior to analysis. Future analysis will use a CHN Analyser and loss-on-ignition.
Northern. Ireland NSI	Source: Agriculture Food and Environmental Science Division(2007) Total Nitrogen and total Carbon in soils - total combustion method. Unpublished Standard Operation Procedure.	Total carbon was measured by elemental analyser but there is no mention in the SOP of pre-treatment of calcareous soils or correction for carbonate.
BioSoil	Source: Forest Research (2006). Lab Manual. Unpublished.	Direct determination of organic carbon was measured by pre-treating soils with hydrochloric acid and subsequent use of an elemental analyser. Indirect determination was carried out by determining total carbon and then correcting for carbonate, which was measured separately.
Environment Agency (National Laboratory Service)	Source: Environment Agency (2007) Determination of total organic Carbon, total Carbon, total Nitrogen and related analytes in soil, sediment and waste. Unpublished Work Instruction.	Direct determination of organic carbon was measured by pre-treating soils with hydrochloric acid and subsequent use of an elemental analyser.
BS 7755-3.8:1995 ISO 10694:1995	Source: British Standards Institute	The carbon present in the soil is oxidised to carbon dioxide by heating the soil to at least 900°C in a flow of oxygen-containing gas that is free from carbon dioxide. The amount of carbon dioxide released is then measured. For the determination of the organic carbon content, any carbonates present are previously removed by treating the soil with hydrochloric acid. Alternatively, if the carbonate content of the examined samples is known and corrections are made for the carbonates present then the organic carbon content is calculated.

Total nitrogen (measurement units: g/kg)

Candidate procedures are reviewed in Table 5.5. It is recommended that the method of combustion as described in the British Standard is used.

Table 5.5 Total nitrogen

Survey	Reference	Description
NSI England and Wales	Not measured.	
Countryside Survey	Source:CEH (2007) Countryside Survey 2007 WP 4 Soil Report Annex 2 Soil laboratory protocol. Unpublished.	Total nitrogen is measured by elemental analyser (dry combustion) on a sub-sample from agate-ball milling
NSIS Scotland	Source: Macaulay Institute for Soil Research (1971) Laboratory Notes on Methods of Soil Analysis. Unpublished Handbook.	Total nitrogen was measured by elemental analyser on finely ground, 2-3 g representative sub-sample derived by coning and quartering <2 mm fraction and milling to approximately 100 mesh (150 µm) in an agate ball mill.
Northern. Ireland NSI	Source: Agriculture Food and Environmental Science (2007) Total Nitrogen and total Carbon in soils - total combustion method. Unpublished Standard Operation Procedure.	The method of dry combustion was used.
BioSoil	Source: Forest Research (2006). Lab Manual. Unpublished.	The method of dry combustion was used.
Environment Agency (National Laboratory Service)	Source: Environment Agency (2007) Determination of total organic Carbon, total Carbon, total Nitrogen and related analytes in soil, sediment and waste. Unpublished Work Instruction.	The method of dry combustion was used.
BS EN 13654-2:2001	Source: British Standards Institute.	The nitrogen in the soil is determined by heating to a temperature of at least 900°C in the presence of oxygen gas. During oxidised combustion, mineral and organic nitrogen compounds produce the oxidation products NOx, in addition to molecular nitrogen (N_2). Copper in the reduction tube quantitatively reduces these nitrogen oxides to N_2 and binds excess oxygen. The amount of nitrogen is then measured by a thermal conductivity detector (TCD).

Available phosphorus (measurement units mg/kg)

Candidate procedures are reviewed in Table 5.6. The existing soil monitoring schemes determine phosphorus on either a mass or volume basis. Knowing the volume of a 5 g mass or the mass of a 5 ml volume would allow some comparison with historical data, although there would be some variation in extraction ratios. Defra report SP0515 (Defra, 2003) comparing soil properties from a range of data sources summarised that "to convert from weight to volume basis requires the use of "bulk density", the weight of soil in a given volume, usually grams per cubic centimetre (g cm^{-3}). Most non-humose soils have a dry bulk density of between 1.0 and 1.4 m g cm^{-3} (Hallett *et al.,* 1995). Humose soils, however, often have densities below 1.0 g/cm^{-3} and peaty soils less than 0.4 g cm^{-3}, therefore, if an extraction method specifies a 10 ml scoop of soil to be taken, the weight may lie between 10 and 14 g for mineral soils but less than 10 g for a humose soil. Soils with a high organic carbon content will therefore contain less of every element than would be expected if a constant weight was taken."

Adopting the ISO standard (sub-sample by weight) would prevent arguments over which option is right and is therefore recommended. Measurement of the laboratory bulk density would allow calculation of a by volume equivalent value. For existing results that were performed on a volume basis, a measurement of a laboratory bulk density offers the option for some comparison.

Table 5.6 Available phosphorus

Survey	Reference	Description
NSI England and Wales	Source: McGrath, S.P. and Loveland, P.J. (1992) The Soil Geochemical Atlas of England and Wales. Blackie Academic and Professional, London.	A 5 ml scoop of air-dry, <2 mm soil was extracted by shaking for 30 minutes with 100 ml of 0.5 mol/l sodium bicarbonate solution. Phosphorus in the filtrate was determined colorimetrically with acid ammonium molybdate solution at 880 nm.
Countryside Survey	Source:CEH (2007) Countryside Survey 2007 WP 4 Soil Report Annex 2 Soil laboratory protocol. Unpublished.	5 g of air-dry, <2 mm soil is extracted by shaking for 30 minutes with 100 ml of 0.5 mol/l sodium bicarbonate solution. Phosphorus in the filtrate is determined colorimetrically with acid ammonium molybdate solution at 880 nm.
NSIS Scotland	Source: Macaulay Institute for Soil Research (1971) Laboratory Notes on Methods of Soil Analysis. Unpublished Handbook.	2.5 g air-dry soil was extracted by shaking for 2 hours with 100 ml 0.5M acetic acid. Phosphorus in filtrate was determined by an Absorptiometer with Truog and Meyer reagent.
Northern. Ireland NSI	Source: Agriculture Food and Environmental Science Division(2007) Determination of extractable Phosphorus in soil using a Skalar San Plus auto analyser. Unpublished Standard Operation Procedure.	A 5 ml scoop of air-dry, <2 mm soil was extracted by shaking for 30 minutes with 100 ml of 0.5 mol/l sodium bicarbonate solution. Phosphorus in the filtrate was determined colorimetrically with acid ammonium molybdate solution at 880 nm.
BioSoil	Not measured.	
BS 7755-3.6:1995 ISO 11263:1994	Source: British Standards Institute	5 g of air-dry, <2 mm soil is extracted by shaking for 30 minutes with 100 ml of 0.5 mol/l sodium bicarbonate solution. Phosphorus in the filtrate is determined colorimetrically with acid ammonium molybdate solution at 880 nm.

Aqua regia extractable metals (measurements units: mg/kg)

Candidate procedures are reviewed in Table 5.7. The methods employed in previous and current monitoring schemes are roughly similar but differ in their precise detail. It is recommended that an inter-laboratory trial is conducted on a set of standard but contrasting samples with a view to the selection of a single protocol for future use and the calibration of this with the various methodologies used previously.

Table 5.7 Aqua regia extractable metals

Survey	Reference	Description
NSI England and Wales	Source: McGrath, S.P. and Loveland, P.J. (1992) The Soil Geochemical Atlas of England and Wales. Blackie Academic and Professional, London.	20 ml of concentrated hydrochloric acid and 5 ml of concentrated nitric acid was added to 2 g of air-dry, finely-ground soil. The sample was then digested for one hour at room temperature, followed by one hour at 105°C, followed by four hours at 140°C (or until the samples were dry). After cooling, 25ml of 0.24 mol/l hydrochloric acid was added and re-warmed to 80°C. The filtrate was analysed by ICP-OES.
Countryside Survey	Source:CEH (2007) Countryside Survey 2007 WP 4 Soil Report Annex 2 Soil laboratory protocol. Unpublished.	30 ml of aqua regia is added to 3 g of finely-ground soil. This is left to stand for 16 hours at room temperature to allow slow oxidation of the organic matter in the soil. The temperature of the reaction mixture is raised slowly until reflux conditions are reached and the sample is maintained at this temperature for two hours. After cooling, the filtrate is analysed by ICP-OES.
NSIS Scotland	Source: McGrath, S.P. and Cunliffe, C.H. 1985. A simplified method for the extraction of the metals Fe, Zn, Cu, Ni, Cd, Pb, Cr, Co and Mn from soils and sewage sludges. Journal of the Science of Food and Agriculture. 36, 794-798.	A 2 g sample of milled soil sample was added to a crucible and placed in a preheated oven at 105^{0}C for a minimum of two hours. After cooling, the crucible was transferred to a muffle furnace set at 450^{o}C and heated for 16 hours, then cooled and added to a digestion tube. 20ml of aqua regia extractant was added and mixed. The temperature was successively raised to 140^{o}C. A further 25 ml of 20% HCl was added, mixed and heated at 80°C. The sample was filtered and the determination made by inductively coupled plasma-mass spectroscopy (ICP-MS).
Northern. Ireland NSI	Source: Agriculture Food and Environmental Science Division(Unpublished). Determination of aqua-regia extractable Cd, Cu, Ni and Zn in soil.	15 ml of concentrated hydrochloric acid and 5 ml of concentrated nitric acid was added to 2 g of air-dry, finely-ground soil. The sample was then digested for three hours at 60°C, followed by one hour at 105°C, followed by 10 hours at 140°C (or until the samples were dry). After cooling, 25 ml 20% hydrochloric acid was added and re-warmed to 80°C. The filtrate was analysed by ICP-OES.
BioSoil	Source: No source is identifiable at present.	21 ml of concentrated hydrochloric acid and 7 ml of concentrated nitric acid was added to 3 g of soil. The reaction mixture was left to stand for 16 hours at room temperature to allow slow oxidation of the organic matter in the soil. The temperature of the reaction mixture was raised slowly until reflux conditions were reached and this temperature maintained for two hours. After cooling the filtrate was analysed.
Environment Agency (National Laboratory Service)	Source: Environment Agency (2007) Determination of metals in soil by inductively coupled plasma optical emission spectrometry (ICP-OES). Unpublished Work Instruction LE M Metals (ICPOES) 01.	7.5 ml of concentrated hydrochloric acid and 2.5 ml of concentrated nitric acid was added to 1 g of soil. The reaction mixture is left to stand for 16 hours at room temperature. The temperature of the reaction mixture is raised to 120°C over 50 minutes and then held at this temperature for 150 minutes. After cooling the filtrate is analysed.
BS 7755-3.9:1995 ISO 11466:1995	Source: British Standards Institute.	20 ml of concentrated hydrochloric acid and 5 ml of concentrated nitric acid was added to 3 g of soil. The reaction mixture was left to stand for 16 hours at room temperature to allow slow oxidation of the organic matter in the soil. The temperature was then raised slowly until reflux conditions were reached and maintained for two hours. After cooling the filtrate was analysed.
BS EN 13657:2002	Source: British Standards Institute.	This describes the aqua regia extraction of a soil sample in a closed microwave digestion system.

Available magnesium and potassium (measurement units mg/kg)

Candidate procedures are reviewed in Table 5.8. The existing soil monitoring schemes determine magnesium and potassium on either a mass or volume basis. Previous comments relating to the effects of bulk density under the section on determination of available phosphorus are relevant here. It is proposed that the BS standard is adopted where a known mass of soil is taken.

Table 5.8 Available magnesium and potassium

Survey	Reference	Description
NSI England and Wales	Source: McGrath, S.P. and Loveland, P.J. (1992) The Soil Geochemical Atlas of England and Wales. Blackie Academic and Professional, London.	A 10 ml scoop of air-dry, <2 mm soil was extracted by shaking for 30 minutes with 50 ml of 1.0 mol/l ammonium nitrate solution. Magnesium and potassium in the filtrate were determined by flame photometry.
Countryside Survey	Not measured.	
NSIS Scotland	Source: Macaulay Institute for Soil Research (1971) Laboratory Notes on Methods of Soil Analysis. Unpublished Handbook.	Exchangeable magnesium and potassium were measured in extracts using 1M ammonium acetate solution at pH7. The concentration of potassium in the extract was determined by flame photometry and the concentration of magnesium determined by AAS.
Northern. Ireland NSI	Source: MAFF, 1986. The Analysis of Agricultural Materials, 3rd edition, Reference Book 427, HMSO, London.	Available potassium and magnesium are extracted from soil using 1M ammonium acetate at pH 7.0. The concentration of potassium in the extract is determined by flame photometry and the concentration of magnesium is determined by AAS.
BioSoil	Not measured	
BS 3882:2007 Specification for topsoil an requirements for use	Source: British Standards Institute	A weighed amount of air-dry, <2 mm soil equivalent to 10 ml of sample was extracted by shaking for 30 minutes with 50 ml of 80 g/l (1.0 mol/l) ammonium nitrate solution. Determine the amount of magnesium and potassium in the filtered extract using a suitably validated method.

Nitrogen mineralisation

No previous UK soil monitoring scheme has measured nitrogen mineralisation. The method has been selected following a recommendation expressed in Environment Agency (2006a).

BS 7755-4.4.3:1997 is recommended as a procedure. This is identical to ISO 14238:1997 Soil quality – Part 4: Biological methods – Section 4.4 Effects of pollutants on microbes – Subsection 4.4.3 Determination of nitrogen mineralisation and nitrification in soils and the influence of chemicals on these processes. The principle of this determination is that the rate or extent of N-mineralisation in aerobic soils is determined by measuring the concentrations of ammonium, nitrite and nitrate released during mineralisation of nitrogen within the soil.

This determination would have to be carried out on field-fresh soil material, and its inclusion in any future monitoring programme would have implications for sampling and sample handling regimes.

The inclusion of this recommended method in this set of protocols should not be taken as a recommendation that this determination is included in any future monitoring exercise.

Bulk density (measurements units: g cm^{-3})

Candidate procedures are reviewed in Table 5.9.

Table 5.9 Bulk density

Survey	Reference	Description
NSI England and Wales	Not measured.	
Countryside Survey	Source:CEH (2007) Countryside Survey 2007 WP 4 Soil Report Annex 2 Soil laboratory protocol. Unpublished.	Bulk density measurements were measured on a 15cm long by 5 cm diameter soil core. One bulk density core is collected from each X plot.
NSIS Scotland	Source: NSIS_2 sampling protocols (Lilly et al, in preparation)	A horizontal bench is exposed by cutting back the face of a soil pit. Metal rings of 210 cm^3 volume carefully carved in to the soil from the surface and cut away by undermining. They are trimmed and soil extruded in to a sample bag. This is repeated to give triplicate samples. The soils are dried at 105° C for 48 hours (or until moisture loss is negligible), weighed and sieved to remove stones. Bulk density is mass to volume ratio, corrected for stones >2 mm to give a value for the fine earth fraction.
Northern. Ireland NSI	Source: Hall *et al* 1977, Soil Survey Tech Monograph No. 9.; Water Retention, Porosity and Density of Field Soils	Bulk density was measured on separate soil cores taken using standard steel cans approximately 5 cm long by 7.5 cm diameter (volume 222 cm^3).
BioSoil	Source: Forest Research (2006). Lab Manual. Unpublished.	Bulk density was measured at some sites. Measurement was made using soil cores with a minimum volume of 100 cm^3 depending on the type of soil being sampled. These were taken from the mineral topsoil (0-10 cm) and five replicates were taken from each sampling site. Determination of the bulk density of the deeper layers is optional.
BS 7755-5.6:1999 ISO 11277:1998	Source: British Standards Institute.	Core samples of known volume are taken with a metal sampling tool. The sample is then dried in an oven, weighed, and the bulk density calculated. The Standard recommends at least six core samples of known volume from each soil layer

Topsoil bulk density is of value as an indicator of soil physical quality in its own right, and samples are needed for both the top and the bottom zones of the topsoil in agricultural soils. In addition, it is required to calculate soil organic carbon density or stock. Thus further sampling depths are recommended for peat soils.

The taking of bulk density cores needs to be part of the overall sampling strategy and recommendations are made as to the depths for sampling under Field Procedures above. The ISO standard can be adopted for the laboratory analysis of these samples but there are significant differences in the number of replicate cores needed for a given sampling depth. Further work is recommended to determine the necessary minimum number of replicate cores. It is recommended that the cores for a given sampling depth are aggregated prior to the laboratory determination of bulk density for cost saving.

Soil archiving

Candidate procedures have been reviewed (Table 5.10). Procedure UKSMS 004:2008 Archiving of Samples has been drafted (Appendix G) and is recommended for adoption. The residue of the dried, sieved and/or milled composite samples will be stored at one or more sites depending on a future decision from the Project Board. The cost associated with the long-term safe storage of sample collections should be noted.

Table 5.10 Soil archiving

Survey	Description
NSI England and Wales	Following the separation of sub-samples for laboratory analysis, sieved and milled sub-samples from each collected bulk sample have been stored in a temperature controlled, purpose-built sample store. Each is held in a plastic bag within an acid-free cardboard box and identified by grid reference and laboratory bar code identifier. Access to the sample collection for valid research purposes is allowed. No soil, once removed from a sample box, is placed back in that box so as to avoid contamination through human error.
Countryside Survey	Soils are air dried and sieved to less than 2 mm and stored in labelled plastic airtight containers, which are archived in numbered batches within plastic boxes. The boxes are stored on shelves on rolling racks within a locked soil archive room. Access to samples is controlled via CEH Lancaster. For CS2007, all samples have been bar-coded. An archive has also been set up for frozen soil samples for subsequent analysis for microbiological determinands and persistent organic pollutants.
NSIS Scotland	Following the separation of sub-samples for laboratory analysis, around 300 g air-dried soil, sieved and milled to <2 mm from each collected bulk sample have been stored in plastic jars with plastic-coated, metal lids in a temperature controlled sample store. The jars of sub-samples are held in a plastic box and identified by grid reference and laboratory ID.
Northern. Ireland NSI	Air-dried (at 30°C) and sieved (<2 mm) soil samples from NSIS1 are stored in plastic pots, which hold maximum amounts of 340g of mineral soil material or 100g of organic soil material. Each pot is labelled with the unique sample identification number and arranged in sample identification number order on trays. These soil samples are now housed along with other soil samples in the National Soil Archive of Scotland. We have recently renovated our archive storage facility and samples are now on purpose-built shelving. Sample splitting and sub-sample preparation is now controlled to ensure that each sub-sample is representative of the original sample, but it is unclear whether similar protocols were followed in the past.
BioSoil	No information on protocols is currently available.

Data management

Information held on field proformas has been captured digitally and incorporated into national information systems alongside sample and analytical data. These site, soil and laboratory analytical data from NSI, NSIS, CS and ECN are stored in a relational database management system with a unique identifier for each sample and OS grid references for each site visited. Long term, managed data storage is therefore assured.

Similar procedures are implemented by all organisations. For example purposes, in Scotland, soil profiles from NSIS_1, sampled between 1978 and 1988, are identified by grid reference, which provides a unique primary key, since, for NSIS_1, no two soil profiles were sampled in the same place. The soil morphological data and site characteristics were either recorded on forms designed for the purpose or on field computers. Textual field descriptions were coded according to an unpublished protocol. Data from the forms were double-entered into computer and cross-checked for typing errors. Soil samples for analysis and archiving are given unique identification numbers and linked to the field data by grid reference, depth and horizon symbols. Analytical data returned from the laboratory were subject to the same double-entry validation procedure. Data were originally stored in DBASE II and transferred to an Oracle®

Relational Database Management System around 1988. Each time data were migrated to a different or newer database software, a range of routines written in the language of the new database were run to validate the data against known values. As an additional check, profile descriptions were produced and validated by the soil surveyor responsible for the data collection. A database of sample material weights is currently being populated to identify how much remains from each sample. The data are now managed by the Institute Soil Data Manager.

Data confidentiality (third party disclosure) restricts access to RSSS and CS grid reference location data, the later under licensing arrangements. Summary data are freely available from the CS2000 report and web pages whilst certain data from earlier surveys are available from the Countryside Information System via the web. Data from the NSI are held in LandIS (Proctor *et al.,* 1998) and can be accessed through licensing arrangements. Bona fide researchers can license the data free from royalties under an agreement between Cranfield University and Defra. Data from NSIS are accessible under a range of licensing arrangements.

It is recommended that data are captured digitally in the field using a robust GPS-linked hand-held device with a database-linked input form for the direct input of site, soil profile and sample information.

All information collected during the monitoring programme including site details and attributes, site and soil images, soil profile descriptions, samples and laboratory data should be held digitally in a relational database. Long term managed data storage, in one or more data centres, is recommended as this will provide adequate data security. Procedure UKSMS_005:2008 proposes a set of stages for establishment of a Soil Monitoring Information Facility.

Public freedom of access to source geo-referenced data on soil quality, particularly metals data, may conflict with the interests of individual land owners and it would be advisable for the data-holders to consider the rights of third-party access to all monitoring information

5.3.3 Outcome for standard operating procedures

The outcome is summarised in Table 5.11. Five new procedures have been drafted (see Appendix G).

Table 5.11 Standard Operating Procedures for a UK soil monitoring network

Procedure	Existing SOP recommended	New SOP drafted
Establishment of a sampling point		UKSMS 001:2008
Site and soil profile description		UKSMS 002:2008
Sample collection & storage		UKSMS 003:2008
Sample preparation	BS 11464:2006	
Soil pH	Modified BS ISO 10390:2005	
Soil organic carbon	Modified BS 7755-3:1995 ISO 10694:1995	
Total nitrogen	BS EN 13654-2:2001	
Available phosphorus	BS 7755-3.6:1005 ISO 11263:1994	

Aqua regia extractable metals	Possible modified BS EN 13657:2002	
Available magnesium and potassium	BS 3882:2007	
Nitrogen mineralisation	BS 7755-4.4.31997 ISO 14238:1997	
Bulk density	Modified BS 7755-5.6:1999 ISO 11277:1998	
Archiving of samples		UKSMS 004:2008
Data management and archiving		UKSMS 005:2008

5.4 Revised costs

Table 5.12 illustrates outline costs for a soil monitoring network based on a stratified random sample of 4000 samples, which are divided such that there are equal numbers of samples in each country and with sampling effort divided equally between the land classes in that country. This decision was reached on the basis that the primary requirement would be to report indicators across land uses in each country, as opposed to a single country statistic or UK level statistics, and reflects outcomes from the preceding sections. The detailed costs were obtained from the information gathered for Section 4 of this report with recalculating to reflect 1000 samples per country. Therefore, the total outline cost is comparable to 4000 sample designs in Section 4, at around £2.6 million for the UK as a whole. The difference now lies in the outline costs for each country, which are accordingly now equal across all four countries (£0.6 million per country).

Table 5.12 Outline costs for a UK Soil Monitoring scheme based upon a stratified random scheme of 4000 sampling locations.

Scale	Individual countries	UK *in total*	
Tasks	1000 samples each	4000 samples	Notes
Project management / office	37,249	55,873	a
Statistical design	25,901	103,604	
Field preparation	22,695	90,780	
Sampling	269,940	1,079,760	
Sample reception	18,873	75,492	
Laboratory work	193,875	775,500	
Archiving of samples	8,872	35,488	b
Information and data archiving	31,048	124,192	
Report and web outputs	90,078	360,312	c
Outline total costs	661,282	2,645,128	

Notes: a = economies of scale if sampling UK as a whole versus individual countries.
b = does not include rental of archive space, but have added pot costs.
c= multiplied reporting by three to reflect reporting on three main indicators (pH, SOC status and change).

5.5 Implementation conclusions

A summary of the Process Map is presented here, however it is envisaged that the implementation phase would use this map in digital form with the capacity to work interactively between the sections of the map. In this format, there is the capacity to revise and update the sections as the requirements for a monitoring scheme develop.

Of the fourteen Standard Operating Procedures that were reviewed, it was considered adequate to apply current ISO or BSI standard as SOPs in nine instances (sample preparation, soil pH, soil organic carbon, total nitrogen, available phosphorus, aqua regia extractable metals, available magnesium and potassium, nitrogen mineralisation, bulk density). Five new SOPs have been devised for the remaining five instances (establishment of a sampling point, site and soil profile description, sample collection & storage, archiving of samples, data management and archiving).

Once the detailed requirements for a UK soil monitoring network have been established, a specific recommendation from this project would be to match up the checklist sections with the sections of the process map and individual standard operating procedures. This would provide a unified set of instructions for a UK soil monitoring network that would act as not only the final specification to initiate the monitoring scheme, but also as a complete historical record.

6 Final conclusions & recommendations

Checklist

At the outset, we established a checklist to assist in the process of implementing a Tier 1 soil monitoring network across UK by setting out the type and level of information required to realise a design for actual deployment, including subsequent process mapping and arranging standard operating procedures. Several knowledge gaps were subsequently addressed by the Stakeholder Workshop but the checklist still remains incomplete.

Recommendations:

- The checklist continues to be developed and updated at both a UK and a country-level so that the checklist becomes a comprehensive record of the monitoring requirements for each country across UK and ultimately the detailed specification of the scheme that is actually deployed. Adoption of this approach for each country as a minimum component of any country-level sampling would help to address future cross-UK comparability of soils information.

Indicator specification tables

As part of the checklist, a set of indicator specification tables were constructed to collate the necessary technical information for all 13 of the UKSIC indicators. This highlighted that there are around 30 different combinations of indicators and soil function with a range of knowledge gaps. The most common of these are appropriate tolerance levels, for the quality measures, and action levels reflecting different stakeholder requirements, particularly at the individual country-level since any scheme will primarily be reporting at this scale.

Tolerance levels are a vital component since no design can be evaluated effectively without this information. The project team implemented tolerance levels to test the design options but these could not reflect all UKSIC indicator/soil function requirements. The outcomes from the results within this report must be considered within this context. Altering the tolerance levels could alter the performance of the individual design options and make some design options more feasible than currently demonstrated. A workshop outcome was that UKSIC will follow up on the knowledge gaps for the indicators, in particular the establishment of appropriate tolerance levels for different purposes.

Recommendations:

- In the first instance, tolerance levels are established for reporting units at the country-level for the indicators deemed essential to a UK soil monitoring network to support completion of sampling designs at the country-level.
- Soil properties only become elevated to actual indicators within the monitoring framework once sufficient information has been established, such as the indicator specification table being complete.
- The indicator specification tables are revised and updated, as part of the checklist, when this information becomes available. Again these tables will act as a comprehensive record of UK soil monitoring requirements.

Canary indicators

Initial consultation with the Project Board identified four canary indicators (SOC, pH, copper, zinc). At the workshop, this was further refined to assessing status and change in both SOC and pH at the UK level within all countries.

Recommendations:

- In the first instance, common approach across the UK will include assessments of status and change in soil pH and SOC in all countries (England, Northern Ireland, Scotland, Wales).
- Where possible, monitoring schemes should include the other UKSIC indicators as supplementary information to obtain data at relevant spatial and temporal scales to determine the effectiveness of assessing both status and change in soil parameters other than carbon. This would also introduce a degree of future proofing for as yet unknown or undefined risks to soil functions or soil health in general.
- Each country should follow the same standard operating procedures to support UK compatibility and comparability of future data. Individual countries can then include additional procedures to meet specific country-level requirements, for example, to obtain results comparable to previous surveys. One example may be sampling horizons in Scotland to achieve comparable data to the NSIS while obtaining a topsoil sample for UK wide compatibility.

Reporting units and sample allocations

Initial consultation with the Project Board identified reporting requirements at the land use level with priorities for classification based on the National Land Use Database classification; NLUD (Land Cover classes were used in this project as a spatial equivalent). At the workshop, a smaller set of reporting units were agreed, reducing the classes from 16 to 7. This will help in identifying the most appropriate sample allocation in the final scheme. Issues were later raised regarding reporting country-level statistics. These would also influence sample allocation with optimal allocation for one purpose not necessarily optimal for other reporting purposes.

UKSIC should reassess the reporting priorities, in particular the relative importance of reporting country-level statistics versus land use statistics within country as this has important implications for sample allocation, precision of results and costs.

Model-based versus design-based options

Our work has shown that the two model-based schemes (grid and optimised grid) were less suitable than the design-based stratified random survey for the specific questions we were addressing, in particular the assessment of status and change in soil organic carbon. In addition, the clustered stratified random scheme required a considerably larger total number of samples than a stratified random scheme without clustering to provide the same precision, although there is of course a saving in terms of the cost of sample collection.

The stratified random scheme is therefore the most promising design. Our findings from comparing model-based and design-based options for a UK soil monitoring network are in line with other published research, in that full geostatistical estimation of means of large areas from primarily grid-based sampling is generally less efficient than design-based estimation from stratified random sampling (Papritz & Webster 1995; Gruijter *et al.*; 2006; Peltoniemi *et al*., 2007). This was most noticeable in the assessment of change in SOC. Since the spatial correlation of change in SOC is weak (and it is this correlation that is exploited in geostatistical estimation) the result is not surprising, but it does have implications for soil monitoring to assess change in indicators.

Our observations from real data confirm previous results from simulation studies that stratification can improve measurements of SOC change (c.f. Saby and Arrouays, 2004; Peltoniemi *et al*., 2007) but there is no information to indicate whether this would hold for other indicators. Although we have found that our model-based schemes were less suitable than a stratified random survey analysed by design-based methods for this project, this is not a reason to criticise or avoid systematic surveys in general since they have the advantage that they achieve good spatial coverage, with proportional representation of the regions of interest.

Recommendations:

- If a completely new monitoring scheme were to be set up, a stratified random sampling scheme would be most appropriate. Stratification should ensure the best spatial coverage possible and is consistent with adequate sampling of all classes.
- Our findings do not support an approach in which reporting units are sampled in proportion to area. In particular, sampling all points on a simple regular grid is not adequate for the specific questions under this study because sample sizes in the rarer reporting units would be too small. The power analyses to date illustrate that equal sample numbers across reporting units would be the most effective. Therefore the results shown from proportion to area can be considered the "worst case" with likely improvements in statistics with schemes based on equal numbers. It is however unlikely to significantly change the fact that the design-based scheme generally performs better, as the underlying spatial and temporal variation in the indicators will not change.
- The exact sample sizes required would depend on the agreed tolerances for agreed reporting requirements and their action levels. These should reflect country-level requirements with agreement of commonalities at a UK level to ensure compatibility.
- More samples will be required than the minimum needed solely to give adequate estimation in the primary reporting units to allow for potential future changes such as land use changes, loss of sampling locations and so on. A minimum contingency of 20 per cent is recommended, however this should be

assessed when the specifications for each country are finalised as individual countries may require greater contingencies if there are significant requirements for secondary reporting or interpretation.

- It may be more difficult to report on new reporting classes in the future if a design-based scheme is selected. This is because the sampling intensity is tailored to the reporting classes identified in advance of the scheme being implemented. However, the risk of this can be reduced by appropriate stratification to ensure good geographic coverage, and the inclusion of more samples than required to provide flexibility.
- A comprehensive assessment of the optimal stratification(s) for individual countries should be carried out once the specifications for each country are finalised as individual countries may require different emphases for sampling to reflect specific environmental conditions or requirements for secondary reporting or interpretation.
- Ultimately our results indicate that there is not a great deal of difference in the costs between the different sampling options with the same sampling intensity, with optimisation providing relatively minor cost savings.
- Complete sampling of a regular grid is not suitable for the proposed Tier 1 soil monitoring scheme because of the requirement to provide estimates of status and change in soil indicators for a range of land uses within countries (the reporting units).
- Although a design-based analysis of a grid survey is possible, there would need to be strong ancillary reasons to favour the use of a grid when starting a Tier 1 monitoring scheme from scratch. This might include a wish to ensure spatial balance in the face of unknown future demands on the scheme (although appropriate stratification in stratified random sampling can also achieve this). One important advantage of this approach would be the opportunity to use soil surveys or monitoring schemes that were originally set up with sampling from a systematic grid. This would have a scientific and practical advantage of building on pre-existing data of not only specific UKSIC soil indicators but also factors such as site characterisations, past land use and so on. The link to pre-existing information should not be underestimated. It would not only have significant costs savings regarding site location and characterisation but this resource base can also be used to address the current knowledge gaps in implementing a UK soil monitoring network across four countries.

Future opportunities

Although there are clear gaps in the availability of soils data to be able to design a comprehensive soil monitoring network, the UK is internationally recognised for the relative wealth of its large-scale spatial and temporal soils information both at the UK and individual regional levels. It has both stratified random and grid-based sampling schemes in place in most countries. These all have soils information dating back to the mid-1970s, a few have subsequently been re-sampled and have produced some of the first large-scale soils change data over an extended time period in the world, while others are currently being re-sampled and will establish the first time series sampling of soils at this scale.

This resource, and its scientific knowledge base, has established the UK at the forefront of national-scale soil monitoring with the information being used to inform development of soil monitoring schemes elsewhere. It would be difficult to justify establishing an entirely new scheme from new locations with no pre-existing data. The question still remains: how can we best use this information to our advantage?

Recommendation:

- There are distinct differences in both the distribution of soil types and how soils are used and managed across the devolved regions. Cross-UK linkages of the available soils information resource would offer opportunities to examine a range of issues in greater detail than possible at individual country-level. Examples include; understanding the impacts of differing land management practises or policies on the soil quality of similar soils in different regions, revising soil C stock information using soil information across regions to establish more accurate figures for all soils across the UK or better understanding how climate change will influence UK soils by being able to look across our entire islands' climatic ranges.
- Cross-linkage, both within UK and internationally, would be greatly helped by establishing a unified UK soil classification, for example, based on the World Reference Base of Soil Resources.

In conclusion, the sponsors of a monitoring scheme must accept that, if they want the most efficient scheme to answer specific questions about particular reporting units, then this will to some extent limit its future flexibility. On the other hand, if they want a sampling scheme that will be most flexible in future, then it will not be ideal for answering specific questions that can be framed now. Any decision-making should be based on full awareness of these differing limitations for future expectations.

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List of abbreviations

AFBI	Agri-Food and Biosciences Institute
BGS	British Geological Survey
BioSS	Biomathematics & Statistics Scotland
C	Carbon
CAP	Common Agricultural Policy
Cd	Cadmium
CEC	Cation Exchange Capacity
CEH	Centre for Ecology and Hydrology
Cl	Cluster
CS	Countryside Survey
CU	Cranfield University
Cu	Copper
defra	Department for Environment, Food and Rural Affairs
EA	Environment Agency
E&W	England and Wales
ENVASSO	Environmental Assessment of Soil for Monitoring
EU	European Union
Ext	Extractable
g	grams
Gr or Grid	Systematic model-based sampling scheme
K	Potassium
kg	kilograms
LCM	Land Cover Map
Min	Mineralisable
Mg	Magnesium
mg	Microgram
MLURI	Macaulay Land Use Research Institute
N	Nitrogen
NHy	Ammonia
Ni	Nickel
NLUD	National Land Use Database
NOx	Nitrogen Oxides
NSI	National Soil Inventory
NSIS	National Soil Inventory of Scotland
Opt	Optomized model-based sampling scheme
P	Phosphorus
PB	Project Board
PLFA	Phospholipid fatty acid
POPs	Persistent Organic Pollutants
RCR	Respiratory control ratio
RRes	Rothamsted Research
RS	Stratified random sampling
RC/RC CLUST	Clustered sampling
S	Sulphur
S1	Sampling intensity of 1000 sites across the UK
S2	Sampling intensity of 2000 sites across the UK
S3	Sampling intensity of 4000 sites across the UK
SEPA	Scottish Environment Protection Agency
SFFS	Sustainable Farming and Food Strategy
SNIFFER	Scotland and Northern Ireland Forum for Environmental Research
SOC	Soil organic carbon
UKCIP	UK Climate Impacts Programme
UKSIC	UK Soil Indicators Consortium
WAG	Welsh Assembly Government
Zn	Zinc

Glossary

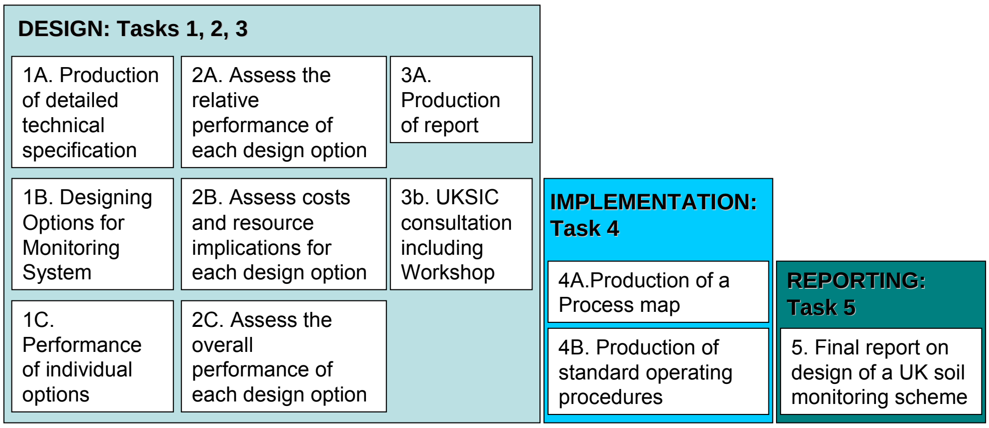
Action levels	The level at which policy is required to be implemented to prevent further degradation.
Adaptive sampling	An adaptive sampling scheme adjusts to take account of emerging information on the variability of change.
Canary Indicator	Priority *indicators* that are known to be critical and therefore must be adequately monitored in a network, irrespective of design. A scheme must be suitable for these priority indicators at least (i.e. able to determine *status* and detect *change* with adequate precision) if the scheme is to be considered for *Tier 1 monitoring.*
Change (of an indicator)	Difference between condition of indicator between different rounds of sampling.
Confidence interval	A pair of values that delimit the interval for which there is a certain probability that the true value of the indicator lies between those values.
Design-based monitoring	A specific approach to designing sampling options where samples are selected using random sampling.
Design options	Specific term used by UKSIC for this project.
Error of variogram estimation	A form of quality estimation of the sample data.
Error variance	Error variance is assumed to be independent of common variance, and a component of the unique variance of a variable.
Estimation variance	This is the mean squared error of an estimate of some random variable (for example, the value of a soil property at an unsampled site, or the mean value of some property within a particular class of land cover). Every estimation method involves an *estimation variance,* which arises due to the fact that the quantity (e.g. mean) to be estimated will generally differ from its estimator (i.e. the function / model used to estimate the unknown population variable). The estimation variance is the expected squared error of the estimate.
Quality measure	Requirements for the statistical performance of each indicator, reflecting the accuracy, precision or reliability of the data. Common measures are the *confidence internal* and *error variance*.
Lag distances	A lag distance is the distance in space between two observations. The lag may also be defined with respect to direction, although we did not do this. In practice we work with lag classes, pairs of observations separated by approximately the same distance
Method of moments	A standard approach to estimating parameters of a frequency distribution from a sample.
Model	Statistical representation of the variation of the properties of interest.
Model based schemes	Model-based schemes select the sampling points purposively,

	that is to select the points such that a given purpose is served best.
Monitoring	Collecting information on soil through repeated or continuous observation in order to determine possible change in soils.
Stationarity	Variables where statistical properties do not change with time.
Point estimate of the variogram	Estimate of *variogram* for a particular *lag*
Predicted Error Variance (PEV)	Measure of precision associated with the prediction method (Webster and Oliver, 1990)
Prediction Variance	Variance of the prediction. This represents the uncertainty about individual predicted data points
Reporting units	The units for which we aim to report mean values of indicators for.
Simulated annealing	a generic probabilistic meta-algorithm for optimization of a function or a set of functions to some criteria.
Spatial variance model	Mathematical model to characterise the variability of an indicator in the spatial dimension
Status (or an indicator)	Condition of an indicator from a specific monitoring interval, typically based on pre-defined domains of interest, units, parameters and quality measures, including tolerances
Tier 1 monitoring network/scheme	A three tier monitoring scheme is envisaged by the UKSIC with only the Tier 1 monitoring being carried out at the national scale. At Tier 1, assessment of the current status and identification of trends in national soil quality are required to be determined.
Tolerance level (d)	What level of uncertainty are end-users prepared to accept from information gained in monitoring
Variogram	A function that relates the variance of the difference of two observations of a variable to the distance between them.

Appendix A

Project Delivery

Figure 1: Organisational diagram of project sub-tasks



DESIGN: Tasks 1, 2, 3

1A. Production of detailed technical specification

1B. Designing Options for Monitoring System

1C. Performance of individual options

2A. Assess the relative performance of each design option

2B. Assess costs and resource implications for each design option

2C. Assess the overall performance of each design option

3A. Production of report

3b. UKSIC consultation including Workshop

IMPLEMENTATION: Task 4

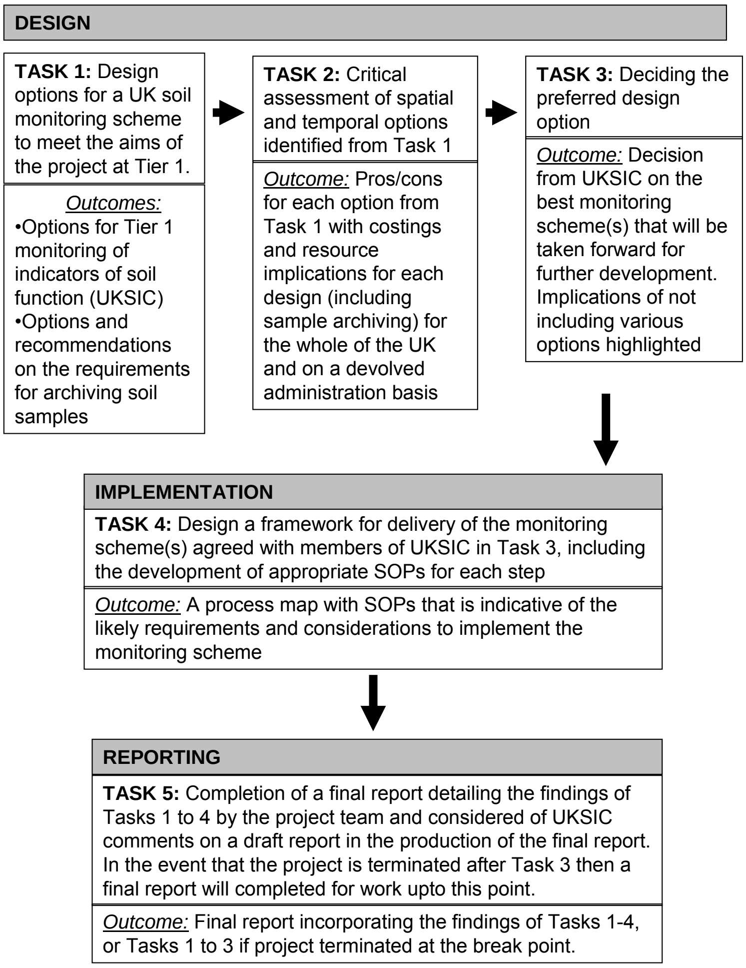
4A.Production of a Process map

4B. Production of standard operating procedures

REPORTING: Task 5

5. Final report on design of a UK soil monitoring scheme

Figure 2: Project tasks and outcomes



DESIGN

TASK 1: Design options for a UK soil monitoring scheme to meet the aims of the project at Tier 1.

Outcomes:
- •Options for Tier 1 monitoring of indicators of soil function (UKSIC)
- •Options and recommendations on the requirements for archiving soil samples

TASK 2: Critical assessment of spatial and temporal options identified from Task 1

Outcome: Pros/cons for each option from Task 1 with costings and resource implications for each design (including sample archiving) for the whole of the UK and on a devolved administration basis

TASK 3: Deciding the preferred design option

Outcome: Decision from UKSIC on the best monitoring scheme(s) that will be taken forward for further development. Implications of not including various options highlighted

IMPLEMENTATION

TASK 4: Design a framework for delivery of the monitoring scheme(s) agreed with members of UKSIC in Task 3, including the development of appropriate SOPs for each step

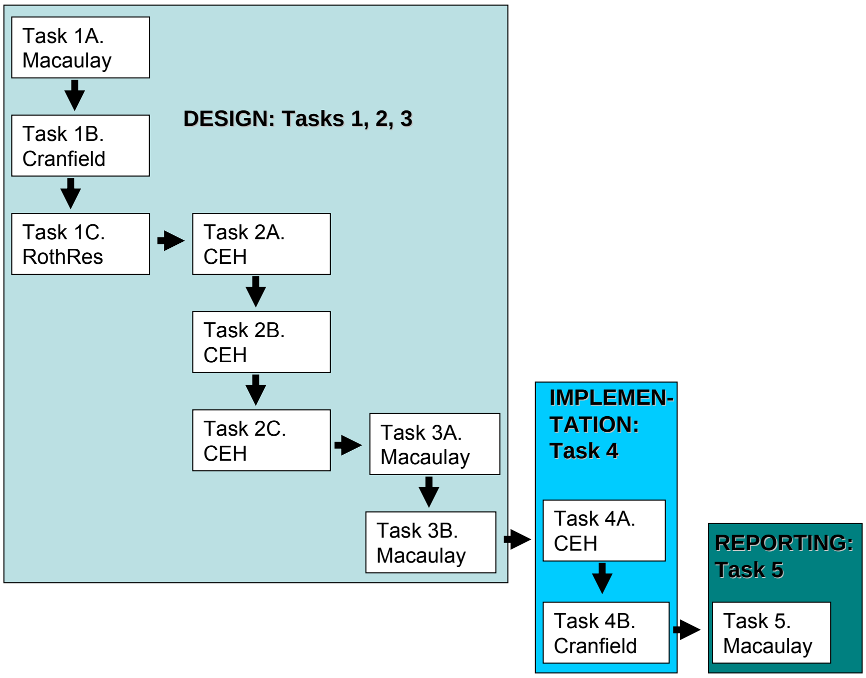
Outcome: A process map with SOPs that is indicative of the likely requirements and considerations to implement the monitoring scheme

REPORTING

TASK 5: Completion of a final report detailing the findings of Tasks 1 to 4 by the project team and considered of UKSIC comments on a draft report in the production of the final report. In the event that the project is terminated after Task 3 then a final report will completed for work upto this point.

Outcome: Final report incorporating the findings of Tasks 1-4, or Tasks 1 to 3 if project terminated at the break point.

Figure 3: Consortium lead responsibilities for project tasks / sub-tasks



Appendix B

Indicator Specification tables

		Functions			
	Indicator	**FF**	**EI**	**SEHB**	**CH**
Section 1.	Soil organic matter content	Y	Y	Y	Y
Section 2.	Soil pH	Y	Y	Y	Y
Section 3.	Total copper	Y	Y		
Section 4.	Total zinc	Y	Y		
Section 5.	Bulk density	Y	Y		
Section 6.	Carbon to nitrogen ratio			Y	
Section 7.	Olsen P / ext. P	Y	Y	Y	
Section 8.	Total nitrogen content	Y	Y		
Section 9.	Total cadmium content	Y			
Section 10.	Potentially mineralisable N			Y	
Section 11.	Total nickel content	Y	Y		
Section 12.	Extractable potassium	Y		Y	
Section 13.	Extractable magnesium	Y			

Shaded areas within the following tables indicate where information requires clarification or confirmation to progress the indicators.

Section 1. Soil organic matter content

Table 1.1. Topsoil organic matter (SFFS headline indicator)

Function	**Food & fibre production**		
Indicator required	**Soil organic matter (SFFS headline indicator)**		
Policy objective	To halt the decline of soil organic matter caused by agricultural practices in vulnerable soils by 2025		
Source	Defra, 2005a (*http://www.defra.gov.uk/farm/policy/sustain/index.htm*)		
Indicator assessment	To determine whether there have been significant losses in soil organic matter (SOM) caused by agricultural practices in vulnerable soils		
Assessment interval	E = start year 2008/09, report on SOM 2010/11 (approx) and again before 2025. All other administrations = 5 yr		
Domains of interest	Devolved administrations and Land uses		
Indicator variable (unit)	Measured values of topsoil soil organic carbon content (g kg^{-1}) reported as organic matter		
Measured variable (unit)	Measured values of topsoil soil carbon content (SOC %) converted using a pedotransfer function (SOC x 1.724)		
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits for specified Land uses, following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)		
Indicator quantity	Status and change in the mean soil organic matter content for agricultural Land uses.		
Type of result	Quantitative: Is soil organic matter content significantly different to previous estimates? Qualitative: Is soil organic matter content progressing towards the targets set for each land use?		
Quality measure (d: tolerance level)	(i) The width of a 95% confidence interval for the true mean SOM (g/kg) is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean SOM (g/kg) is 2d or less		
Land use (other than Land Cover classes)	Arable / rotational grass	Permanent managed grass	Managed semi-natural grassland
Action level (mean)	Progression to 50 g kg^{-1} for E&W	Progression to 75 g kg^{-1} for E&W	Progression to 220 g kg^{-1} for E&W
Soil depth	0-15 cm topsoil		
Sampling procedure	Direct comparison with NSI E&W requires sampling using Soil Survey for England and Wales sub-sampling by auger.		
Analytical method	SOC by method comparable to LOI + Walkely Black, but preferably dry combustion method		
Archiving	Air-dried 2 mm sieved soil sample		
Additional information	Change relative to previous values (NSI E&W); probably moving to stock estimates with measurement of bulk density; data for Government Office Regions on the "would like" list. Comparable to methodology listed in Defra SFFS headline indicator Factsheet.		

Table 1.2. Soil organic matter ranges (Food & Fibre production)

Function	**Food & fibre production**															
Indicator required	**Ranges of soil organic matter**															
Policy objective	To halt the decline of soil organic matter caused by agricultural practices in vulnerable soils by 2025															
Source	http://www.defra.gov.uk/environment/land/soil/research/indicators/pdf/ea-meeting060213.pdf; Verheijen et al. *Soil Use and Management* (2005)															
Indicator assessment	Soil organic matter values falling below the given ranges would prompt further investigation															
Assessment interval																
Domains of interest	Devolved administrations and Land uses															
Indicator variable (unit)	Measured values of soil organic matter content reported as organic matter (%)															
Measured variable (unit) measurement	Measured values of soil organic carbon content (%)															
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution															
Indicator quantity	Mean status in soil organic matter content in specified agricultural Land uses for a range of soil texture and rainfall classes															
Type of result	Qualitative: Do soil organic matter values fall below Action level values?															
Quality measure (d: tolerance level)	(i) The width of a 95% confidence interval for the true mean SOM (g/kg) is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean SOM 9g/kg) is 2d or less															
Land use (other than Land Cover classes)	Arable / rotational grass								Permanent managed grass							
Supplementary information: accumulated annual precipitation	< 650 mm/yr				650-800 mm/yr				800-1100 mm/yr							
Supplementary information: clay content (%)	0-10	10-20	20-30	30-40	0-10	10-20	20-30	30-40	0-10	10-20	20-30	30-40	0-10	10-20	20-30	30-40
Action level: mean (%)	1.9	2.6	3.3	4.1	2.1	3.3	4.3	4.3	3.6	4.1	4.7	5.9	4.5	5.7	6.6	6.6
Soil depth	0-15 cm topsoil															
Sampling procedure	Direct comparison with NSI E&W requires sampling using Soil Survey for England and Wales sub-sampling by auger; Intact core sample required for comparison with Countryside Survey.															
Analytical method	SOM by method comparable to LOI and Walkely Black, but preferably dry combustion methods															
Archiving	Air-dried 2 mm sieved soil sample															
Additional information	Probably moving to stock estimates with measurement of bulk density; data for Government Office Regions on the “would like” list. Need to include all soils especially if soil C stock assessments are needed. Do not want to exclude urban soils but technical issues to be resolved.															

Table 1.3 Soil organic matter content for Environmental Interactions

Function	**Environmental Interactions**									
Indicator required	**SOC as an indicator of environmentally relevant and important functions which determine water acceptance, water storage and bio-filtration**									
Policy objective	To maintain soil organic matter content to support water storage and pollution attenuation (e.g. prevent pesticide leaching).									
Source	Environment Agency (2006a)									
Indicator assessment	To determine whether soil carbon falls out with the values and ranges adopted for the protection of environmental interactions in a range of Land uses									
Assessment interval										
Domains of interest	Devolved administrations and Land uses									
Indicator variable (unit)	Measured values of topsoil soil carbon content (%)									
Measured variable (unit)	Measured values of topsoil soil carbon content (%)									
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits for specified Land uses, following transformation to normal distribution									
Indicator quantity	Status of soil organic matter content in different Land uses									
Type of result	Qualitative: (a) Is soil carbon content below 3% in soils receiving pesticides (b) Is soil carbon content outside the SOC ranges for the different Land uses									
Quality measure (d: tolerance level)	(i) The width of a 95% confidence interval for the true mean SOM (g/kg) is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean SOM (g/kg) is 2d or less									
Land use (other than Land Cover classes)	All soils receiving pesticide additions	Grassland soils NOT receiving pesticide additions	calcareous grassland	broad-leaved woodland	coniferous woodland	improved grassland	acid grassland	bog	dwarf shrub heath	bracken
Action level(%); i. minimum ii. ranges iii. min – max.	3 (i)	2 to 9 (ii)	13.1 - 21.2 (iii)	2.16 - 56.0 (iii)	1.74-56.6 (iii)	1.85-53.6 (iii)	3.7 - 56.4 (iii)	6.6 - 56.7 (iii)	4.2 - 56.8 (iii)	4 - 55.3 (iii)
Soil depth	0-15 cm topsoil									
Sampling procedure	(i) & (ii) comparable to Soil Survey sub-sampling by auger (iii) comparable to intact core sample (CS2000).									
Analytical method	SOM by method comparable to LOI and Walkely Black, but preferably dry combustion methods									
Archiving	Air-dried 2 mm sieved soil sample									
Additional information										

Table 1.4 Soil organic matter content for Supporting ecological habitat and biodiversity

Function	**Supporting ecological habitat and biodiversity**
Indicator required	SOC as an indicator of change in terrestrial habitats
Policy objective	To determine status and change in soil carbon for different Land uses
Source	Environment Agency (2006b)
Indicator assessment	To determine whether there have been any significant changes in soil carbon
Assessment interval	
Domains of interest	Devolved administrations and Land uses
Indicator variable (unit)	Measured values of soil organic carbon content (%)
Measured variable (unit)	Measured values of soil organic carbon content (%)
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits, following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)
Indicator quantity	Status and change in the mean topsoil organic carbon content for different Land uses.
Type of result	Quantitative: Is topsoil carbon content significantly different to previous topsoil carbon estimates? Qualitative: Is any change in topsoil carbon content +/- 20% from previous values for each Land use (other than Land Cover classes)
Quality measure (d: tolerance level)	(i) The width of a 95% confidence interval for the true mean SOM (g/kg) is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean SOM (g/kg) is 2d or less
Land use (other than Land Cover classes)	For all Land uses (NLUD groups)
Action level	Change in - / + 20% from the previous sampling for each land use . [The action level is not clear, for example is this a change of 50% to 30% in carbon content or a change of 10% (i.e. 20% of 50%), or 20% change in SOC weight g/kg?]
Soil depth	0-15 cm topsoil
Sampling procedure	To be confirmed: comparable to Soil Survey sub-sampling by auger and / or comparable to intact core sample (CS2000).
Analytical method	SOC by method comparable to LOI + Walkely Black, but preferably dry combustion methods
Archiving	Air-dried 2 mm sieved soil sample
Additional information	

Table 1.5 Soil organic matter content for protection of archaeological remains

Function	**Cultural heritage & archaeology**
Indicator required	**SOC as an indicators of changing soil conditions for the the preservation of buried artefacts**
Policy objective	Organic matter within the topsoil is relevant to cultural heritage preservation in terms of erosion risk and general health and resilience of the soil. Soil organic matter in mineral soils is important in maintaining aggregate stability hence resistance to erosion, soil structural properties hence drainage characteristics, and cation exchange capacity hence soil nutrient status. Soil organic matter content is a good general indicator of soil quality for cultural heritage preservation providing an integrated indicator of resource health.
Source	Davidson & Wilson (2006).
Assessment interval	
Indicator assessment	Changes in organic matter content interpreted in terms of erosion potential, redox potential, and microbial activity. An increase in organic matter can be seen as beneficial in terms of erosion resistance and moisture holding characteristics.
Domains of interest	Devolved administrations and Land uses
Indicator variable (unit)	Measured values of soil organic carbon content (%)
Measured variable (unit)	Measured values of soil organic carbon content (%)
Indicator parameter	- Mean, standard deviation and upper and lower 95 confidence limits for specified Land uses, following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)
Indicator quantity	Status and change in the mean topsoil organic carbon content for different Land uses
Type of result	Quantitative: Is topsoil carbon content significantly different to previous topsoil carbon estimates? Qualitative: Is any change in topsoil carbon content +/- 20% from previous values for each Land use (other than Land Cover classes)
Quality measure (d: tolerance level)	(i) The width of a 95% confidence interval for the true mean SOM (g/kg) is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean SOM (g/kg) is 2d or less
Land use (other than Land Cover classes)	
Action level	Change in - / + 20% from the previous sampling for each Land use (other than Land Cover classes) [The action level is not clear, for example is this a change of 50% to 30% in carbon content or a change of 10% (i.e. 20% of 50%), or 20% change in SOC weight g/kg?]
Soil depth	0-15 cm topsoil
Sampling procedure	Following Soil Survey for E&W procedures
Analytical method	SOM by method comparable to LOI and Walkely Black, but preferably dry combustion methods
Archiving	Air-dried 2 mm sieved soil sample
Additional information	Further work required to determine Action levels and requirements for supplementary information. Soil, geological, climate and Land use (other than Land Cover classes) change data will be needed for national and regional interpretation of soil indicators

Section 2. Soil pH

Table 2.1. soil pH for Food and fibre production

Function	**Food & fibre production**								
Indicator required	**Soil pH**								
Policy objective	Maintenance of soil pH for food and fibre production								
Source	Environment Agency (2006b)								
Indicator assessment	To determine whether soil pH values fall above or below action levels indicating that function may be compromised								
Assessment interval									
Domains of interest	Devolved administrations and land use								
Indicator variable (unit)	pH units								
Measured variable (unit)	pH units								
Indicator parameter	- Mean, standard deviation and upper and lower 95%confidence limits following transformation to normal distribution								
Indicator quantity	Values above or below trigger values Mean status and change for specified reporting classes								
Type of result	Quantitative: Is soil pH significantly different to previous estimates? Qualitative: Is soil pH lower than the action levels?								
Quality measure (d: tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean is 2d of less								
Land use (other than Land Cover classes)	Arable & horticultural land (NLUD)		Improved grassland (NLUD)		Vegetables		Forestry		
Supplementary information (soil type)	mineral	peaty	mineral	peaty	mineral	peaty	mineral	peaty	calcareous
Action levels	<6.5	<5.8	<6	<5.3	<6.5	<5.8	<3.5	<3.5	>8.4
Soil depth	Topsoil : 0-15 plus and 0 to 7.5 cm for permanent grassland								
Sampling procedure	Following Soil Survey for England and Wales procedures (25 sub samples). Defra CoGAP specifies at least 25 sub-samples								
Analytical method	In both water and $CaCl_2$ for compatibility with current data, but comparative values are for water.								
Archiving	Air-dried 2 mm sieved soil sample								
Additional information									

Table 2.2. Soil pH for environmental interactions

Function	**Environmental interaction**			
Indicator required	**Soil pH**			
Policy objective	Prevention of loss in capacity to retain metals or biofiltering / microbial function			
Source	Environment Agency (2006a)			
Indicator assessment	To determine whether soil pH values fall above or below trigger values indicating that function may be compromised			
Assessment interval				
Domains of interest	Devolved administrations and Land uses			
Indicator variable (unit)	pH units			
Measured variable (unit)	pH units			
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution			
Indicator quantity	Values above or below trigger values Mean status and change for specified reporting classes			
Type of result	Qualitative: Is soil pH below the action levels?			
Quality measure (d: tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less			
Land use (other than Land Cover classes)				
Functions	Metal retention		Microbial function / biofiltering	
Supplementary information (soil types)	Mineral	Peaty	Mineral	Peaty
Action levels	<6	<5.5	<5	<4.5
Soil depth	Topsoil : 0-15 cm (arable) and 0 to 7.5 cm (permanent grassland)			
Sampling procedure	Following Soil Survey for England and Wales procedures (25 sub samples)			
Analytical method	(ISO 10390:2005)			
Archiving	Air-dried 2mm sieved soil sample			
Additional information				

Table 2.3. Soil pH for support of ecological habitat

Function	**Support of ecological habitat**				
Indicator required	**Soil pH**				
Policy objective	Maintenance of soil pH for support of ecological habitats				
Source	Environment Agency (2006b)				
Indicator assessment	To determine whether soil pH values fall above or below trigger values indicating that function may be compromised				
Assessment interval					
Domains of interest	Devolved administrations and land uses				
Indicator variable (unit)	pH units				
Measured variable (unit)	pH units				
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits (for land uses) following transformation to normal distribution				
Indicator quantity	Mean status for reporting classes				
Type of result	Qualitative: Is soil pH above or below the action levels?				
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less.				
Land use (other than Land Cover classes)	Calcareous grassland	Mesotrophic grassland	Acid grassland	Dwarf shrub heath	
Supplementary information (soil type)				Mineral	Peaty
Action level	<7	<5>7	>5	>4.5	>5
Soil depth	Topsoil : 0-15 cm (arable) and 0 to 7.5 cm (permanent grassland)				
Sampling procedure	Following Soil Survey for England and Wales procedures				
Analytical method	In water (ISO 10390:2005)				
Archiving	Air-dried 2 mm sieved soil sample				
Additional information					

Table 2.3 Continued

Function	**Support of ecological habitat**
Indicator required	**Soil pH**
Policy objective	Maintenance of soil pH for support of ecological habitats
Source	Environment Agency (2006b)
Indicator assessment	To determine whether soil pH values fall above or below trigger values indicating that function may be compromised
Assessment interval	
Domains of interest	Devolved administrations and Land uses
Indicator variable (unit)	pH units
Measured variable (unit)	pH units
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)
Indicator quantity	Mean status and change for specified reporting classes
Type of result	Quantitative: Is change in soil pH greater than 0.5 pH units
Quality measure (*d:* tolerance level)	(i) 95%confidence that the true mean of the indicator lies within *d* units of the estimated mean (ii) 95% confidence that an estimate of the mean change in the indicator will have a confidence interval of +/- *d* units
Land use (other than Land Cover classes)	
Action level	Change in - / + 0.5 pH units from the previous sampling for the relevant reporting classes
Soil depth	Topsoil : 0-15 cm (arable) and 0 to 7.5 cm (permanent grassland)
Sampling procedure	Following Soil Survey for England and Wales procedures
Analytical method	In water (ISO 10390:2005)
Archiving	Air-dried 2 mm sieved soil sample
Additional information	

Table 2.4. Soil pH for cultural heritage and archaeology

Function	**Cultural heritage & archaeology**
Indicator required	**Soil pH**
Policy objective	Maintenance of soil pH to prevent risk to buried archaeological
Source	Environment Agency (2006b)
Assessment interval	
Indicator assessment	To determine whether there has been as significant change in soil pH values since previous sampling
Domains of interest	Devolved administrations and Land uses
Indicator variable (unit)	pH units
Measured variable (unit)	pH units
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)
Indicator quantity	Mean status and change for specified reporting classes Values are above or below 0.5 pH units of the previous means for specified reporting classes
Type of result	Quantitative: Is change in soil pH greater than 0.5 pH units
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean is 2d or less
Land use (other than Land Cover classes)	
Action level	Change in - / + 0.5 pH units from the previous sampling for the relevant reporting classes
Soil depth	Topsoil : 0-15 cm (arable) and 0 to 7.5 cm (permanent grassland)
Sampling procedure	Following Soil Survey for England and Wales procedures
Analytical method	In water (ISO 10390:2005)
Archiving	Air-dried 2 mm sieved soil sample
Additional information	

Section 3. Total copper content

Table 3.1. Copper content in soils (Food & fibre production)

Function	**Food & fibre production**			
Indicator required	**Total Copper (Cu)**			
Policy objective	Prevention of damage to soil fertility from high concentrations of copper			
Source	The Sludge (Use in Agriculture) Regulations 1989 / 1993. Sewage sludge regulations for England and Wales, Scotland and Northern Ireland. Exceedance according to sludge regulations required			
Indicator assessment	Exceedance of maximum concentrations (totals) in UK soils following sewage sludge applications (MAFF, 1993)			
Assessment interval				
Domains of interest	Devolved administrations and Land uses			
Indicator variable (unit)	Measured values of topsoil total copper content (mg kg^{-1})			
Measured variable (unit)	Measured values of topsoil total copper content (mg kg^{-1})			
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)			
Indicator quantity	- Mean status for specified reporting classes - Exceedance for specified reporting classes			
Type of result	Quantitative: Does the soil metal concentration exceed the action levels?			
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean is 2d or less (iii) 95% confidence that the true mean falls outside the action levels by *d* units or more			
Land use (other than Land Cover classes)				
Supplementary information (soil pH in water)	5.0 – 5.5	5.5 – 6.0	6.0 – 7.0	> 7.0
Action level (mean mg kg^{-1})	80	100	135	200
Soil depth	0-15 cm topsoil for arable soils and 0 – 7.5 cm for grasslands			
Sampling procedure	Following Soil Survey for England and Wales procedures			
Analytical method	Total concentrations by aqua regia digest			
Archiving	Air-dried 2 mm sieved soil sample			
Additional information				

Table 3.2. Copper content in soils (Environmental interactions)

Function /Risk	**Environmental interactions**
Indicator required	**Potential ecological risk from copper (Cu)**
Policy objective	To identify potential ecological risk to soils from soil Cu concentrations
Source	Environment Agency, 2008. Guidance on the Use of Soil Screening Values for Assessing Ecological Risks Science Report – SC070009/SR.
Indicator assessment	Whether the Risk Characterisation Ratio (RCR) exceeds the value of 1 which indicates a potential risk to soil from soil Cu concentrations and thus further investigation is warranted
Assessment interval	
Domains of interest	Devolved administrations and Land uses
Indicator variable (unit)	RCR (n/a)
Measured variable (unit)	mg kg^{-1}
Indicator parameter	Average RCR for individual reporting classes
Indicator quantity	RCR exceeding 1 for the specified reporting classes
Type of result	(i) Does the soil metal concentration exceed the action level for each reporting class (ii) The proportion of samples that exceed the RCR 1 in each reporting class (obtained from RCR per sample location)
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean RCR is 2d or less
Land use (other than Land Cover classes)	
Supplementary information	Total Cu (mg kg^{-1}) from aqua regia digests Measured soil pH in water Measured clay content (%) Organic matter content (derived from measured SOC x 1.724) Soil type (textural class) Measured CEC – or empirically derived from pH, OM and clay
Action level	Action level ≥ 1
Source	ECI (2007) European Union Risk Assessment Report on Copper, copper(ii)sulphate, pentahydrate, copper(i)oxide, copper(ii)oxide, dicopper chloride trihydroxide. Voluntary risk assessment, draft February 2007. European Copper Institute. Obtained from: http://ecb.jrc.it/esis/index.php?PGM=ora
Soil depth	Topsoil : 0 – 15 cm
Sampling procedure	Following Soil Survey for England and Wales procedures
Archiving	Air-dried 2 mm sieved soil sample
Analytical method	Appropriate analytical methods required for supplementary information e.g. estimated total Cu concentrations from aqua regia digests
Additional information	RCR is derived using the Soil Screening decision tool spreadsheet and the input values detailed in the supplementary information section

Section 4. Total zinc content

Table 4.1. Zinc content in soils (Food & fibre production)

Function	**Food & fibre production**			
Indicator required	**Total Zinc (Zn)**			
Policy objective	Prevention of damage to soil fertility from high concentrations of zinc			
Source	The Sludge (Use in Agriculture) Regulations 1989 / 1993. Sewage sludge regulations for England and Wales, Scotland and Northern Ireland. Exceedance according to sludge regulations required			
Indicator assessment	Exceedance of maximum concentrations (totals) in UK soils following sewage sludge applications (MAFF, 1993)			
Assessment interval				
Domains of interest	Devolved administrations and Land uses			
Indicator measurement	Measured values of total zinc (mg kg^{-1})			
Indicator unit	Measured values of total zinc (mg kg^{-1})			
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)			
Indicator quantity	- Mean status for specified reporting classes - Exceedance for specified reporting classes			
Type of result	Quantitative: Does the soil metal concentration exceed the action levels?			
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean is 2d or less (iii) 95% confidence that the true mean falls outside the action levels by *d* units or more			
Land use (other than Land Cover classes)				
Supplementary information (soil pH in water)	5.0 – 5.5	5.5 – 6.0	6.0 – 7.0	> 7.0
Action level (mean mg kg^{-1})	200	250	300	450
Soil depth	0-15 cm topsoil for arable soils and 0 – 7.5 cm for grasslands			
Sampling procedure	Following Soil Survey for England and Wales procedures			
Analytical method	Total concentrations by aqua regia digest			
Archiving	Air-dried 2 mm sieved soil sample			
Additional information				

Table 4.2. Zinc content in soils (Environmental interactions)

Function /Risk	**Environmental interactions**
Indicator required	**Potential ecological risk from zinc**
Policy objective	To identify potential ecological risk to soils from soil Zn concentrations
Source	Environment Agency, 2008. Guidance on the Use of Soil Screening Values for Assessing Ecological Risks Science Report – SC070009/SR.
Indicator assessment	Whether the Risk Characterisation Ratio (RCR) exceeds the value of 1 which indicates a potential risk to soil from soil Zn concentrations and thus further investigation is warranted
Assessment interval	
Domains of interest	Devolved administrations and Land uses
Indicator variable (unit)	RCR (n/a)
Measured variable (unit)	mg kg^{-1}
Indicator parameter	Average RCR for individual reporting classes
Indicator quantity	RCR exceeding 1 for the specified reporting classes
Type of result	(i) Does the soil metal concentration exceed the action level (ii) Proportion of the samples that exceed the RCR 1 in each reporting class
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean RCR is 2d or less
Land use (other than Land Cover classes)	
Supplementary information	Total Zn (mg kg^{-1}) from aqua regia digests Measured soil pH in water Measured clay content (%) Organic matter content (derived from measured SOC x 1.724) Soil type (textural class) Measured CEC – or empirically derived from pH, OM and clay
Action level	Action level ≥ 1
Source	The Netherlands (2004) European Union Risk Assessment Report on Zinc metal, zinc(ii)chloride, zinc sulphate, zinc distearate, zinc oxide, trizinc bis(orthophosphate). . Prepared by The Netherlands, RIVM on behalf of the European Union. Obtained from: http://ecb.jrc.it/esis/index.php?PGM=ora
Soil depth	Topsoil : 0 – 15 cm
Sampling procedure	Following Soil Survey for England and Wales procedures
Analytical method	Appropriate analytical methods required for supplementary information e.g. estimated total Zn concentrations from aqua regia digests
Archiving	Air-dried 2 mm sieved soil sample
Additional information	RCR is derived using the Soil Screening decision tool spreadsheet and the input values detailed in the supplementary information section

Section 5. Topsoil bulk density

Table 5.1a. Topsoil bulk density for food and fibre production

Function	**Food and Fibre Production**		
Indicator required	**Bulk density**		
Policy objective	Determine whether there is any change in soil bulk density indicating potential risk of soil compaction and impairment of soil function		
Source	Environment Agency (2006b)		
Indicator assessment	Significant change in bulk density indicating potential risk of soil compaction thus warranting further investigation. Also significant change in bulk density will have consequences for other soil indicators (e.g. SOC).		
Assessment interval			
Domains of interest	Devolved administrations and Land uses		
Indicator variable (unit)	Measured values of topsoil bulk density (Mg m^{-3})		
Measured variable (unit)	Measured values of topsoil bulk density (Mg m^{-3})		
Indicator parameter	- Mean, standard deviaiton and upper and lower 95% confidence limits (for reporting classes) following transformation to normal distribution		
Indicator quantity	- Mean status for specified reporting classes		
Type of result	Quantitative: Does the soil bulk density exceed the action levels?		
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) 95% confidence that the true mean falls outside the action levels by *d* units or more		
Land use (other than Land Cover classes)	Arable & horticultural (NLUD)		Improved grassland (NLUD)
Supplementary information	Mineral soil / Calcareous	Peaty	
Action level	>1.3	>1	>1.3
Soil depth	0-15 cm topsoil (corresponding to SOC depth). Other depths maybe required for fuller assessment of BD		
Sampling procedure	Intact core method (Hall et al., 1977); sub-sample number dictated by N for SOC in first instance		
Analytical method	Dried soil volume (105°C)		
Archiving	n/a		
Additional information			

Table 5.1b. Topsoil bulk density for food and fibre production

<table>
<tr><th>Function</th><th colspan="14">Food and Fibre Production</th></tr>
<tr><td>**Indicator required**</td><td colspan="14">**Bulk density**</td></tr>
<tr><td>Policy objective</td><td colspan="14">Determine whether there is any change in soil bulk density indicating potential risk of soil compaction and impairment of soil function. Productivity is compromised in very low density soils because of possible low water holding capacity and nutrient deficiencies.</td></tr>
<tr><td>Source</td><td colspan="14">Environment Agency (2006b)</td></tr>
<tr><td>Indicator assessment</td><td colspan="14">Significant change in bulk density indicating potential risk of soil compaction thus warranting further investigation. Also significant change in bulk density will have consequences for other soil indicators (e.g. SOC).</td></tr>
<tr><td>Assessment interval</td><td colspan="14"></td></tr>
<tr><td>Domains of interest</td><td colspan="14">Devolved administrations and land uses</td></tr>
<tr><td>Indicator variable (unit)</td><td colspan="14">Measured values of topsoil bulk density (Mg m^{-3})</td></tr>
<tr><td>Measured variable (unit)</td><td colspan="14">Measured values of topsoil bulk density (Mg m^{-3})</td></tr>
<tr><td>Indicator parameter</td><td colspan="14">- Mean, standard deviaiton and upper and lower 95% confidence limits following transformation to normal distribution</td></tr>
<tr><td>Indicator quantity</td><td colspan="14">- Mean status for specified reporting classes
- Exceedance of Action level for reporting classes</td></tr>
<tr><td>Type of result</td><td colspan="14">Quantitative: Does the soil bulk density exceed the action levels?</td></tr>
<tr><td>Quality measure (*d:* tolerance level)</td><td colspan="14">(i) The width of a 95% confidence interval for the true mean is 2d or less, or
(ii) 95% confidence that the true mean falls outside the action levels by *d* units or more</td></tr>
<tr><td>Land use (other than Land Cover classes)</td><td colspan="7">Tilled land (arable / ley)</td><td colspan="7">Untilled land</td></tr>
<tr><td>Supplementary information (organic matter content %)</td><td><2</td><td>2-3</td><td>3-4</td><td>4-5</td><td>5-6</td><td>6-8</td><td>>8</td><td><2</td><td>2-3</td><td>3-4</td><td>4-5</td><td>5-6</td><td>6-8</td><td>>8</td></tr>
<tr><td>Action level</td><td>1.6</td><td>1.5</td><td>1.4</td><td>1.3</td><td>1.25</td><td>1.2</td><td>1.0</td><td>1.5</td><td>1.4</td><td>1.35</td><td>1.25</td><td>1.2</td><td>1.15</td><td>1.0</td></tr>
<tr><td>Soil depth</td><td colspan="14">0-15 cm topsoil (corresponding to SOC depth). Other depths maybe required for fuller assessment of BD</td></tr>
<tr><td>Sampling procedure</td><td colspan="14">Intact core method (Hall et al., 1977); sub-sample number dictated by N for SOC in first instance</td></tr>
<tr><td>Analytical method</td><td colspan="14">Dried soil volume (105°C)</td></tr>
<tr><td>Archiving</td><td colspan="14">n/a</td></tr>
<tr><td>Additional information</td><td colspan="14"></td></tr>
</table>

Table 5.2. Topsoil bulk density for environmental interactions

Function	**Environmental Interactions**						
Indicator required	**Bulk density**						
Policy objective	Determine whether there is any change in soil bulk density indicating potential risk of soil compaction and impairment of soil function						
Source	Environment Agency (2006a)						
Indicator assessment	Significant change in bulk density indicating potential risk of soil compaction thus warranting further investigation. Also significant change in bulk density will have consequences for other soil indicators (e.g. SOC).						
Assessment interval							
Domains of interest	Devolved administrations and Land uses						
Indicator variable (unit)	Measured values of topsoil bulk density (Mg m^{-3})						
Measured variable (unit)	Measured values of topsoil bulk density (Mg m^{-3})						
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution						
Indicator quantity	- Mean status and change for specified reporting classes - Exceedance for specified reporting classes						
Type of result	Quantitative: Does the soil bulk density exceed the action levels?						
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) 95% confidence that the true mean falls outside the action levels by *d* units or more						
Land use (other than Land Cover classes)	Calcareous grassland	Mesotrophic grassland		Acid grassland		Dwarf shrub heath	
Supplementary information	Calcareous	Mineral	Peaty	Mineral	Peaty	Mineral	Peaty
Action level	>1.3	>1.3	>1.0	>1.3	>1.0	>1.3	>1.0
Soil depth	0-15 cm topsoil (corresponding to SOC depth). Other depths maybe required for fuller assessment of BD						
Sampling procedure	Intact core method (Hall et al., 1977); sub-sample number dictated by N for SOC in first instance						
Analytical method	Dried soil volume (105°C)						
Archiving	n/a						
Additional information							

Section 6. Carbon to nitrogen ratio

Table 6.1 Carbon to nitrogen ratio environmental interactions

<table>
<tr><th>Function</th><th colspan="10">Environmental Interactions</th></tr>
<tr><td>Indicator required</td><td colspan="10">Soil carbon to nitrogen ratio (C:N)</td></tr>
<tr><td>Policy objective</td><td colspan="10"></td></tr>
<tr><td>Source</td><td colspan="10">Environment Agency (2006a); CS2000</td></tr>
<tr><td>Indicator assessment</td><td colspan="10"></td></tr>
<tr><td>Assessment interval</td><td colspan="10"></td></tr>
<tr><td>Domains of interest</td><td colspan="10">Devolved administrations and Land uses</td></tr>
<tr><td>Indicator variable (unit)</td><td colspan="10">Ratio of C% and N%</td></tr>
<tr><td>Measured variable (unit)</td><td colspan="10">C% and N%</td></tr>
<tr><td>Indicator parameter</td><td colspan="10"></td></tr>
<tr><td>Indicator quantity</td><td colspan="10">Envelope of values and direction of change defined by number deviating from specified ranges for each stratification</td></tr>
<tr><td>Type of result</td><td colspan="10">Qualitative</td></tr>
<tr><td>Quality measure (<i>d:</i> tolerance level)</td><td colspan="10"></td></tr>
<tr><td>Land use (other than Land Cover classes)</td><td>Arable & horticulture</td><td>Improved grassland</td><td>Neutral grassland</td><td>Acid grassland</td><td>Calcareous grassland</td><td>Broad-leaved woodland</td><td>Coniferous woodland</td><td>Bracken</td><td>Dwarf shrub heath</td><td>Bog</td></tr>
<tr><td>Action level <i>(are min-max ranges appropriate?)</i></td><td>9-13</td><td>10-12</td><td>10-14</td><td>14-21</td><td>11-14</td><td>12-17</td><td>16-26</td><td>13-18</td><td>19-29</td><td>20-31</td></tr>
<tr><td>Soil depth</td><td colspan="10">0-15 cm topsoil</td></tr>
<tr><td>Sampling procedure</td><td colspan="10">[Unknown – in first instance assume comparable to CS2000 for Action level]</td></tr>
<tr><td>Analytical method</td><td colspan="10">Comparable to total combustion</td></tr>
<tr><td>Archiving</td><td colspan="10">Air-dried 2 mm sieved soil sample</td></tr>
<tr><td>Additional information</td><td colspan="10"></td></tr>
</table>

Section 7. Phosphorus content (Olsen P)

Table 7.1 Phosphorus content (Olsen P) for food & fibre production

Function	**Food and Fibre Production**		
Indicator required	**Extractable phosphorus**		
Policy objective	Maintenance of a balanced and adequate supply of essential nutrients, including potassium for crop production. Particular care should be taken to avoid the build up of unnecessarily high levels of phosphorus in soil. *The Water Code(MAFF PB0587)* advises that soil P levels should not be raised above those necessary for economic crop production		
Source	http://www.defra.gov.uk/farm/environment/land-manage/nutrient/fert/rb209/index.htm)		
Indicator assessment	Are soil phosphorus levels being maintained at the levels required for plant production?		
Assessment interval			
Domains of interest	Devolved administrations and land use		
Indicator variable(units)	Measured values of Olsen P (mg l^{-1})		
Measured variable (units)	Measured values of Olsen P (mg l^{-1})		
Indicator parameter	- Mean, standard deviaiton and upper and lower 95% confidence limits following transformation to normal distribution		
Indicator quantity	- Mean status for specified reporting classes - Exceedance for specified reporting classes		
Type of result	Quantitative: are the soil phosphorus levels below the index of 2?		
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) 95% confidence that the true mean falls outside the action levels by *d* units or more		
Land use (other than Land Cover classes)	Arable and forage crops	Grassland	Vegetables
Supplementary information	Mineral, peaty and calcareous soil types have higher end range values (not required if Action level remains bottom of index 2)		
Action level	Below bottom of index 2: <16 mg l^{-1}		Below bottom of index 2: <26 mg l^{-1}
Soil depth	0-15 cm topsoil		
Sampling procedure	Following Soil Survey for England and Wales procedures (25 sub samples) tbc		
Analytical method	Olsen P		
Archiving	Air-dried 2 mm sieved soil sample		
Additional information			

Table 7.2 Phosphorus content (avail P) environmental interactions

Function	**Environmental Interactions**
Indicator required	**Extractable phosphorus (avail P)**
Policy objective	Values above Action level indicate increased potential for P leaching to water
Source	Environment Agency (2006a)
Indicator assessment	Values above Action level indicate increased potential for P leaching to water
Assessment interval	
Domains of interest	Devolved administrations and Land uses
Indicator variable(units)	Measured values (mg l^{-1}(plus mg kg^{-1}))
Measured variable (units)	Measured values (mg l^{-1}(plus mg kg^{-1}))
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)
Indicator qunatity	- Mean status for specified reporting classes - Exceedance for specified reporting classes *spring measurement only*
Type of result	Quantitative: are the soil phosphorus levels above the action level
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean is 2d or less (iii) 95% confidence that the true mean falls outside the action levels by d units or more
Land use (other than Land Cover classes)	
Supplementary information	
Action level	For soluble P leaching >60 mg l^{-1} However depends upon soil type and land use
Soil depth	0-15 cm topsoil
Sampling procedure	Following Soil Survey for England and Wales procedures
Analytical method	Olsen P (0.5M $NaHCO^3$) ; measured in a sodium bicarbonate soil extract at pH 8.5 (Olsen's P)
Archiving	Air-dried 2 mm sieved soil sample
Additional information	

Table 7.3 Phosphorus content (Olsen P) for supporting ecological habitats and biodiversity

Function	**Supporting ecological habitats and biodiversity**
Indicator required	**Extractable phosphorus**
Policy objective	Prevention of excessive soil phosphorus levels to prevent damage to ecological habitats
Source	Environment Agency (2006b)
Indicator assessment	To determine whether soil phosphorus values exceed the action levels indicating that function may be compromised
Assessment interval	
Domains of interest	Devolved administrations and Land uses
Indicator variable(units)	Measured values of Olsen P (mg l^{-1})
Measured variable (units)	Measured values of Olsen P (mg l^{-1})
Indicator parameter *(must reflect that this is a change indicator not status*)	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)
Indicator quantity	- Mean status and change for specified reporting classes
Type of result	Quantitative: Is change in soil phosphorus greater than 5 mg l^{-1}
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean is 2d or less (iii) 95% confidence that the true mean falls outside the action levels by *d* units or more
Land use (other than Land Cover classes)	
Supplementary information	
Action level	Δ -/+ 5 mg l^{-1} from previous sampling period
Soil depth	0-15 cm topsoil
Sampling procedure	Following Soil Survey for England and Wales procedures
Analytical method	Olsen P
Archiving	Air-dried 2 mm sieved soil sample
Additional information	

Section 8. Total nitrogen content

Table 8.1 Total nitrogen content for food and fibre production

Function	**Food and Fibre Production**		
Indicator required	**Total nitrogen content**		
Policy objective	Nitrogen an essential soil nutrient for plant growth		
Source	Environment Agency (2006b)		
Indicator assessment	Monitor for depletion in soil nitrogen stock. For total nitrogen, it was thought that the relevance of this as an indicator lay in its use to monitor the depletion of nitrogen stocks in soils. Although an understanding of the scale of potential depletion could only be gained after a number of repeat samples over an extend time period. It was suggested that broad ranges of 'normality' may be used to initially gauge changes		
Assessment interval			
Domains of interest	Devolved administrations and Land uses		
Indicator variable (units)	Measured values (%)		
Measured variable (units)	Measured values (%)		
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution		
Indicator quantity	- Mean status and change for specified reporting classes - Values outwith broad ranges of "normality"		
Type of result	Qualitative : i. Are soil nitrogen contents failing outwith the action levels ii. What proportion of soil samples fall outside these intervals		
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) 95% confidence that the true mean falls outside the action levels by *d* units or more		
Land use (other than Land Cover classes)			
Supplementary information (soil type)	Mineral	Organic	Peats
Action level (%)	0.1 – 0.4	0.4 – 1.2	> 1.2
Soil depth	0-15 cm topsoil		
Sampling procedure	Following Soil Survey for England and Wales procedures		
Analytical method	Assume comparable to Soil Survey E&W laboratory methods		
Archiving	Air-dried 2 mm sieved soil sample		
Additional information			

Section 9. Total cadmium content

Table 9.1 Cadmium content in soils for food and fibre production

Function	**Food & fibre production**
Indicator required	**Total Cadmium (Cd)**
Policy objective	Prevention of damage to soil fertility from high concentrations of Cd
Source	The Sludge (Use in Agriculture) Regulations 1989 / 1993. Sewage sludge regulations for England and Wales, Scotland and Northern Ireland. Exceedance according to sludge regulations required
Indicator assessment	Exceedance of maximum concentrations (totals) in UK soils following sewage sludge applications (MAFF, 1993)
Assessment interval	
Domains of interest	Devolved administrations and Land uses
Indicator variable(unit)	Measured values (mg kg^{-1})
Measured variable (unit)	Measured values (mg kg^{-1})
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)
Indicator quantity	- Mean status and change for specified reporting classes - Exceedance for specified reporting classes
Type of result	Quantitative: Does the soil metal concentration exceed the action level?
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean is 2d or less (iii) 95% confidence that the true mean falls outside the action levels by *d* units or more
Land use (other than Land Cover classes)	
Supplementary information	
Action level (mean mg kg^{-1})	3 mg kg^{-1}
Soil depth	0-15 cm topsoil for arable soils and 0 – 7.5 cm for grasslands
Sampling procedure	Following Soil Survey for England and Wales procedures
Analytical method	Total concentrations by aqua regia digest
Archiving	Air-dried 2 mm sieved soil sample
Additional information	

Section 10. Potentially mineralisable N

Table 10.1 Potentially mineralisable N for supporting ecological habitats

Function	**Supporting ecological habitat**
Indicator required	Potentially mineralisable N (PMN)
Policy objective	Nitrogen is a macronutrient essential to the growth of plants. Perturbations to its cycle will affect the flow of N through soil-plant microbial systems. The availability of mineralisable N has potential as an indicator of soil quality.
Source	Environment Agency (2006b)
Indicator assessment	
Assessment interval	
Domains of interest	Devolved administrations and Land uses
Indicator variable (unit)	
Measured variable (unit)	
Indicator parameter	
Indicator quantity	
Type of result	
Quality measure (*d:* tolerance level)	
Land use (other than Land Cover classes)	Record Land use (other than Land Cover classes) at time of sampling
Action level	
Soil depth	0-15 cm topsoil
Sampling procedure	Following Soil Survey for England and Wales procedures
Analytical method	c.f. Drinkwater *et al.*, (1996) : follow ISO standard operating procedures
Archiving	
Additional information	

Section 11. Total nickel content

Table 11.1 Total nickel content (Ni)

Function	**Food & fibre production**			
Indicator required	**Total Nickel (Ni)**			
Policy objective	Prevention of damage to soil fertility from high concentrations of Ni			
Source	The Sludge (Use in Agriculture) Regulations 1989 / 1993. Sewage sludge regulations for England and Wales, Scotland and Northern Ireland. Exceedance according to sludge regulations required			
Indicator assessment	Exceedance of maximum concentrations (totals) in UK soils following sewage sludge applications (MAFF, 1993)			
Assessment interval				
Domains of interest	Devolved administrations and Land use			
Indicator variable(unit)	Measured values (mg kg^{-1})			
Measured variable (unit)	Measured values (mg kg^{-1})			
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)			
Indicator quantity	- Mean status for specified reporting classes - Exceedance for specified reporting classes			
Type of result	Quantitative: Does the soil metal concentration exceed the action levels?			
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean is 2d or less (iii) 95% confidence that the true mean falls outside the action levels by *d* units or more			
Land use (other than Land Cover classes)				
Supplementary information (soil pH in water)	5.0 – 5.5	5.5 – 6.0	6.0 – 7.0	> 7.0
Action level (mean)	50	60	75	110
Soil depth	0-15 cm topsoil			
Sampling procedure	Following Soil Survey for England and Wales procedures			
Analytical method	Total concentration by aqua regia digest			
Archiving	Air-dried 2 mm sieved soil sample			
Additional information				

Table 11.2 Potential ecological risk from Ni for environmental interactions

Function /Risk	**Environmental interactions**
Indicator required	**Potential ecological risk from Ni**
Policy objective	To identify potential ecological risk to soils from soil Ni concentrations
Source	Environment Agency, 2008. Guidance on the Use of Soil Screening Values for Assessing Ecological Risks Science Report – SC070009/SR.
Indicator assessment	Whether the Risk Characterisation Ratio (RCR) exceeds the value of 1 which indicates a potential risk to soil from soil Ni concentrations and thus further investigation is warranted
Assessment interval	
Domains of interest	Devolved administrations and Land uses
Indicator variable (unit)	RCR (n/a)
Measured variable (unit)	mg kg^{-1}
Indicator parameter	Average RCR for individual reporting classes
Indicator quantity	RCR exceeding 1 for the specified reporting classes
Type of result	(i) Does the soil metal concentration exceed the action level (ii) Proportion of the samples that exceed the RCR 1 in each reporting class
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean RCR is 2d or less
Land use (other than Land Cover classes)	
Supplementary information	Total Ni (mg kg^{-1}) from aqua regia digests Measured soil pH in water Measured clay content (%) Organic matter content (derived from measured SOC x 1.724) Soil type (textural class) Measured CEC – or derived from pH, OM and clay
Action level	RCR ≥ 1
Source	Denmark (2007) European Union Risk Assessment Report on Nickel, Nickel Sulphate, Nickel Carbonate, Nickel Chloride, Nickel Dinitrate, Denmark, Draft report October 2007. Prepared by Denmark, Danish Environmental Protection Agency on behalf of the European Union Obtained from: http://ecb.jrc.it/esis/index.php?PGM=ora
Soil depth	Topsoil : 0 – 15 cm
Sampling procedure	Following Soil Survey for England and Wales procedures
Analytical method	Appropriate analytical methods required for supplementary information e.g. estimated total Ni concentrations from aqua regia digests
Archiving	Air-dried 2 mm sieved soil sample
Additional information	RCR is derived using the Soil Screening decision tool spreadsheet and the input values detailed in the supplementary information section

Section 12. Extractable potassium

Table 12.1 Extractable potassium for food and fibre production

Function	**Food and Fibre Production**		
Indicator required	**Extractable Potassium (ext. K)**		
Policy objective	Maintenance of a balanced and adequate supply of essential nutrients, including potassium for crop production.		
Source	http://www.defra.gov.uk/farm/environment/land-manage/nutrient/fert/rb209/index.htm)		
Indicator assessment	Soils at risk if measured values for ext K are below the action levels		
Assessment interval			
Domains of interest	Devolved administrations and Land uses		
Indicator variable(unit)	Measured values (mg l^{-1})		
Measured variable (unit)	Measured values (mg l^{-1})		
Indicator parameter (*status or change or both?)*	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)		
Indicator quantity	- Mean status for specified reporting classes - Exceedance for specified reporting classes		
Type of result	Quantitative: Are soil potassium levels lower than the action levels		
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean is 2d or less (iii) 95% confidence that the true mean falls outside the action levels by *d* units or more		
Land use (other than Land Cover classes)	Arable and forage	Grassland	Vegetables
Supplementary information			
Action level	<121	<121	<181
Soil depth	0-15 cm topsoil		
Sampling procedure	Following Soil Survey for England and Wales procedures		
Analytical method	Ammonium nitrate (*The Analysis of Agricultural Materials (MAFF RB427)*		
Archiving	Air-dried 2 mm sieved soil sample		
Additional information			

Table 12.2 Extractable potassium for the support of ecological habitat and biodiversity

Function	**Support of ecological habitat and biodiversity**
Indicator required	**Extractable Potassium (ext. K)**
Policy objective	Maintenance of a balanced and adequate supply of essential nutrients, for habitat maintenance
Source	Environment Agency (2006b)
Indicator assessment	Broad assessment warrants further investigation if measured values -/+ 50 mg l^{-1} of previous values.]
Assessment interval	
Domains of interest	Devolved administrations and Land uses
Indicator variable(unit)	Measured values (mg l^{-1})
Measured variable (unit)	Measured values (mg l^{-1})
Indicator parameter	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)
Indicator quantity	- Mean status for specified reporting classes - Deviation from previous sampling by -/+ 50 mg l^{-1} for specified reporting classes
Type of result	Qualitative: Is the change in soil potassium concentrations greater than the action levels
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean is 2d or less (iii) 95% confidence that the true mean falls outside the action levels by *d* units or more
Land use (other than Land Cover classes)	
Supplementary information	
Action level	Δ -/+ 50 mg l^{-1} from previous sampling period
Soil depth	0-15 cm topsoil
Sampling procedure	Following Soil Survey for England and Wales procedures
Analytical method	Ammonium nitrate (*The Analysis of Agricultural Materials (MAFF RB427)*)
Archiving	Air-dried 2 mm sieved soil sample
Additional information	

Section 13. Extractable magnesium

Table 13.1 Extractable magnesium for food and fibre production

Function	**Food and Fibre Production**		
Indicator required	**Extractable Magnesium (ext. Mg)**		
Policy objective	Maintenance of a balanced and adequate supply of essential nutrients, including magnesium for crop production.		
Source	http://www.defra.gov.uk/farm/environment/land-manage/nutrient/fert/rb209/index.htm)		
Indicator assessment	Soils at risk if measured values for ext Mg are below the action levels		
Assessment interval			
Domains of interest	Devolved administrations and Land uses		
Indicator variable(unit)	Measured values (mg l^{-1})		
Measured variable (unit)	Measured values (mg l^{-1})		
Indicator parameter *(status or change?)*	- Mean, standard deviation and upper and lower 95% confidence limits following transformation to normal distribution - Estimated change at 95% confidence since last sampling (or earlier samplings)		
Indicator quantity	- Mean status and change for specified reporting classes - Exceedance for specified reporting classes		
Type of result	Quantitative: Are soil magnesium levels lower than the action levels		
Quality measure (*d:* tolerance level)	(i) The width of a 95% confidence interval for the true mean is 2d or less, or (ii) The width of a 95% confidence interval for true change in mean is 2d or less (iii) 95% confidence that the true mean falls outside the action levels by *d* units or more		
Land use (other than Land Cover classes)	Arable and forage	Grassland	Vegetables
Supplementary information			
Action level	<26	<26	<51
Soil depth	0-15 cm topsoil		
Sampling procedure	Following Soil Survey for England and Wales procedures		
Analytical method	Mg O by Ammonium nitrate (*The Analysis of Agricultural Materials (MAFF RB427))*		
Archiving	Air-dried 2 mm sieved soil sample		
Additional information			

Appendix C

Number of available observations of each indicator in each land cover class in the datasets used by this project.

Table C1 Number of observations of each indicator by Land Cover class in the National Soil Inventory (England)

Land Cover Class	Bog	Dwarf shrub heath	Broad-leaved / mixed woodland	Coniferous woodland	Improved grassland	Semi-natural grass	Arable & horticulture	Built up areas & gardens
NSI in England	5	6	8	9	10	11	14	15
pH	43	77	274	93	1487	383	2010	270
SOC	43	80	275	94	1499	397	2029	273
Bulk density	0	0	0	0	0	0	0	0
Olsen P	43	77	274	92	1484	382	2008	270
Total N	0	0	0	0	0	0	0	0
Cu	43	80	275	94	1500	397	2032	274
Cd	43	80	275	94	1500	397	2032	274
Zn	43	80	275	94	1500	397	2032	274
Ni	43	80	275	94	1500	397	2032	274
Mg	43	77	274	93	1487	383	2010	270
K	43	77	274	93	1487	383	2010	270
Min N	0	0	0	0	0	0	0	0
C/N ratio	0	0	0	0	0	0	0	0
Change SOC	14	45	103	41	537	156	639	45

Table C2 Number of observations of each indicator by Land Cover class in the National Soil Inventory (Scotland)

Land Cover Class	Bog	Dwarf shrub heath	Montane habitats	Broad-leaved / mixed woodland	Coniferous woodland	Improved grassland	Semi-natural grass	Arable & horticulture	Built up areas & gardens
NSIS	5	6	7	8	9	10	11	14	15
pH	32	217	41	11	81	131	114	68	2
SOC	32	216	41	11	81	131	114	67	2
Bulk density	0	0	0	0	0	0	0	0	0
Olsen P	0	0	0	0	0	0	0	0	0
Total N	32	215	41	11	81	131	114	67	2
Cu	29	211	41	11	81	130	111	68	2
Cd	29	211	41	11	81	130	111	68	2
Zn	29	211	41	11	81	130	111	68	2
Ni	29	211	41	11	81	130	111	68	2
Mg	32	217	41	11	81	131	114	68	2
K	32	217	41	11	81	131	114	68	2
Min N	0	0	0	0	0	0	0	0	0
C/N ratio	32	215	41	11	81	131	114	64	2
change SOC	0	0	0	0	0	0	0	0	0

Table C3 Number of observations of each indicator by Land Cover class in the National Soil Inventory (Wales)

Land Cover Classes	Dwarf shrub heath	Broad-leaved / mixed woodland	Coniferous woodland	Improved grassland	Semi-natural grass	Built up areas & gardens
NSI in Wales	6	8	9	10	11	15
pH	28	15	67	403	219	15
SOC	29	15	69	414	225	15
Bulk density	0	0	0	0	0	0
Olsen P	28	15	67	406	219	15
Total N	0	0	0	0	0	0
Cu	29	15	69	417	225	15
Cd	29	15	69	417	225	15
Zn	29	15	69	417	225	15
Ni	29	15	69	417	225	15
Mg	28	15	67	403	219	15
K	28	15	67	403	219	15
Min N	0	0	0	0	0	0
C/N ratio	0	0	0	0	0	0
Change SOC	13	6	27	158	91	8

Table C4 Number of observations of each indicator by Land Cover class in the National Soil Inventory (Northern Ireland)

Land Cover Classes	Bog	Dwarf shrub heath	Coniferous woodland	Improved grassland	Semi-natural grass	Built up areas & gardens
NSINI (AFBI)	5	6	9	10	11	15
pH	74	65	63	4939	456	29
SOC	18	19	18	313	55	2
Bulk density	2	1	0	137	10	1
Olsen P	74	65	63	4939	456	29
Total N	18	19	18	317	56	2
Cu	74	65	63	4939	456	29
Cd	74	65	63	4939	456	29
Zn	74	65	63	4939	456	29
Ni	74	65	63	4939	456	29
Mg	74	65	63	4939	456	29
K	74	65	63	4939	456	29
Min N	0	0	0	0	0	0
C/N ratio	18	19	18	313	55	2
Change SOC	0	0	0	0	0	0

Table C5 Number of observations of each indicator by Land Cover class from Countryside Survey 2000 (England)

Land Cover Class	Bog	Dwarf shrub heath	Broad-leaved / mixed woodland	Coniferous woodland	Improved grassland	Semi-natural grass	Arable & horticulture	Built up areas & gardens
CS in England	5	6	8	9	10	11	14	
pH	10	10	45	15	146	42	208	35
SOC	10	10	45	14	145	40	205	35
Bulk density	0	0	0	0	0	0	0	0
Olsen P	6	7	44	12	127	33	191	34
Total N	10	10	45	14	145	40	205	35
Cu	10	10	45	15	145	40	205	35
Cd	10	10	45	15	145	40	205	35
Zn	10	10	45	15	145	40	205	35
Ni	10	10	45	15	145	40	205	35
Mg	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0
Min N	0	0	0	0	0	0	0	0
C/N ratio	10	10	45	14	145	40	205	35

Table C6 Number of observations of each indicator by Land Cover class from Countryside Survey 2000 (Scotland)

Land Cover Class	Bog	Dwarf shrub heath	Montane habitats	Broad-leaved / mixed woodland	Coniferous woodland	Improved grassland	Semi-natural grass	Arable & horticulture	Built up areas & gardens
CS in Scotland	5	6	7	8	9	10	11	14	15
pH	35	116	14	5	58	96	78	34	0
SOC	33	111	13	5	57	97	76	34	0
bulk density	0	0	0	0	0	0	0	0	0
Olsen P	28	87	12	5	48	92	65	33	0
Total N	33	111	13	5	57	97	76	34	0
Cu	34	113	13	5	58	97	76	34	0
Cd	34	113	13	5	58	97	76	34	0
Zn	34	113	13	5	58	97	76	34	0
Ni	34	113	13	5	58	97	76	34	0
Mg	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0
Min N	0	0	0	0	0	0	0	0	0
C/N ratio	33	111	13	5	57	97	76	34	0

Table C7 Number of observations of each indicator by Land Cover class from Countryside Survey 2000 (Wales)

Land Cover Classe	dwarf shrub heath	Broad-leaved / mixed woodland	Coniferous woodland	Improved grassland	Semi-natural grass	Built up areas & gardens
CS in Wales	6	8	9	10	11	15
pH	5	2	5	46	30	0
SOC	5	2	5	44	30	0
Bulk density	0	0	0	0	0	0
Olsen P	0	2	5	35	14	0
Total N	5	2	5	44	30	0
Cu	5	2	5	45	30	0
Cd	5	2	5	45	30	0
Zn	5	2	5	45	30	0
Ni	5	2	5	45	30	0
Mg	0	0	0	0	0	0
K	0	0	0	0	0	0
Min N	0	0	0	0	0	0
C/N ratio	5	2	5	44	30	0

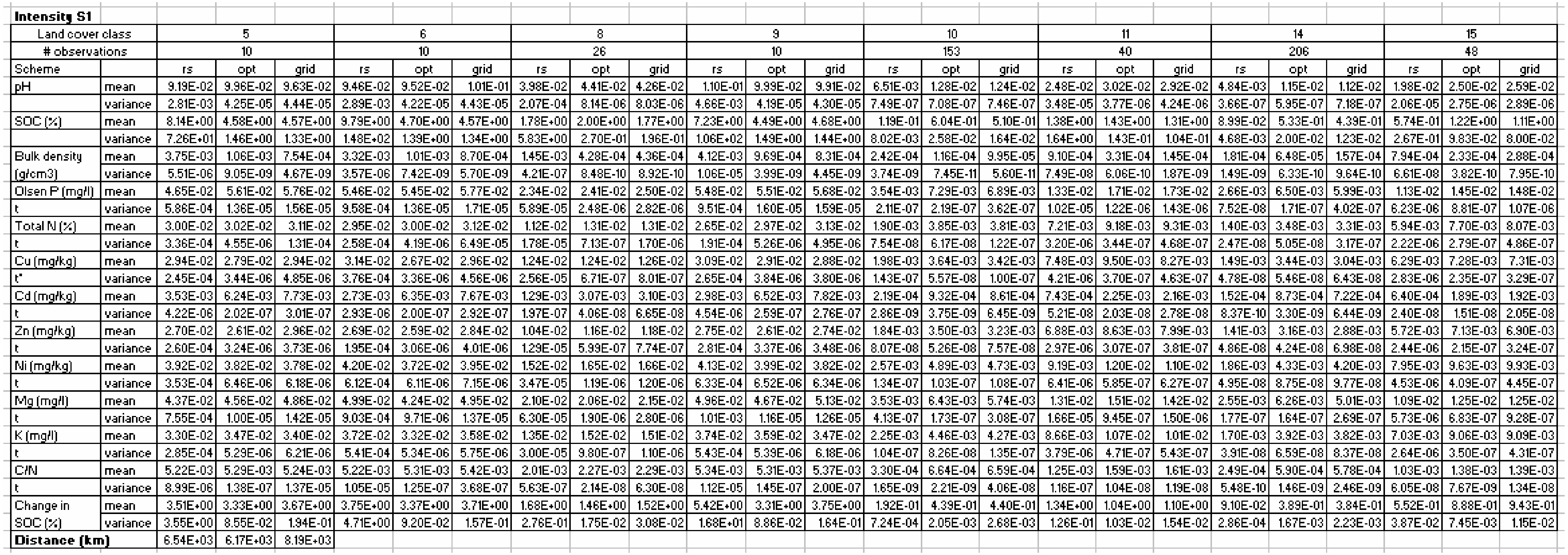
Appendix D

Prediction variances for mean values of indicators and Distance Travelled

mean:- mean prediction variance
variance:- variance of prediction variance
t:- indicator has been log transformed to remove skew
t*:- 1 has been added to indicator before log transform to avoid taking log of zero
rs:- Random stratified sampling (design-based)
opt:- Optimized sampling (model-based)
grid:- Systematic grid based sampling (model-based)
crs:- Clustered random stratified sampling
Distance:- Minimum travelling distance to collect all observations
Units refer to untransformed variables

England

Intensity S1

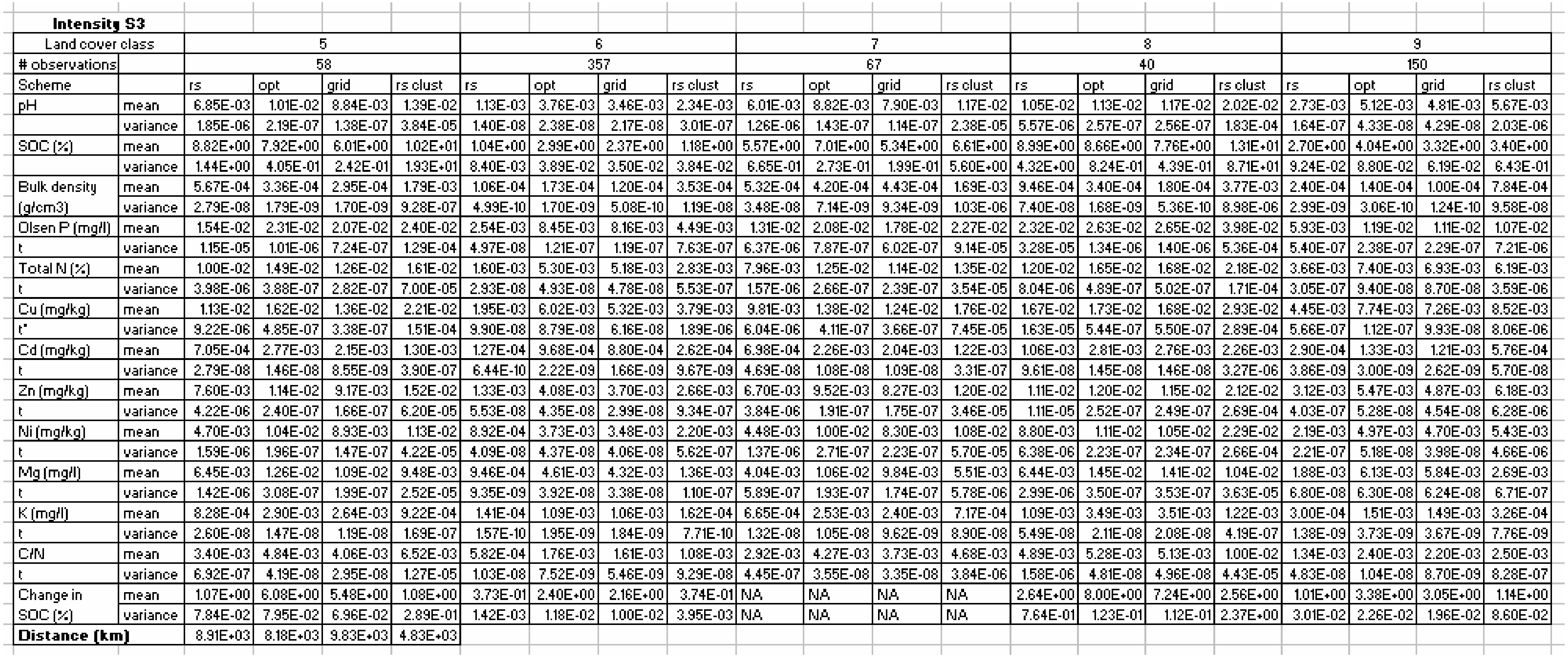


Intensity S1																									
Land cover class		5			6			8			9			10			11			14			15		
# observations		10			10			26			10			153			40			206			48		
Scheme		rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid
pH	mean	9.19E-02	9.96E-02	9.63E-02	9.46E-02	9.52E-02	1.01E-01	3.98E-02	4.41E-02	4.26E-02	1.10E-01	9.99E-02	9.91E-02	6.51E-03	1.28E-02	1.24E-02	2.48E-02	3.02E-02	2.92E-02	4.84E-03	1.15E-02	1.12E-02	1.98E-02	2.50E-02	2.59E-02
	variance	2.81E-03	4.25E-05	4.44E-05	2.89E-03	4.22E-05	4.43E-05	2.07E-04	8.14E-06	8.03E-06	4.66E-03	4.19E-05	4.30E-05	7.49E-07	7.08E-07	7.46E-07	3.48E-05	3.77E-06	4.24E-06	3.66E-07	5.95E-07	7.18E-07	2.06E-05	2.75E-06	2.89E-06
SOC (%)	mean	8.14E+00	4.58E+00	4.57E+00	9.79E+00	4.70E+00	4.57E+00	1.78E+00	2.00E+00	1.77E+00	7.23E+00	4.49E+00	4.68E+00	1.19E-01	6.04E-01	5.10E-01	1.38E+00	1.43E+00	1.31E+00	8.99E-02	5.33E-01	4.39E-01	5.74E-01	1.22E+00	1.11E+00
	variance	7.26E+01	1.46E+00	1.33E+00	1.48E+02	1.39E+00	1.34E+00	5.83E+00	2.70E-01	1.96E-01	1.06E+02	1.49E+00	1.44E+00	8.02E-03	2.58E-02	1.64E-02	1.64E+00	1.43E-01	1.04E-01	4.68E-03	2.00E-02	1.23E-02	2.67E-01	9.83E-02	8.00E-02
Bulk density	mean	3.75E-03	1.06E-03	7.54E-04	3.32E-03	1.01E-03	8.70E-04	1.45E-03	4.28E-04	4.36E-04	4.12E-03	9.69E-04	8.31E-04	2.42E-04	1.16E-04	9.95E-05	9.10E-04	3.31E-04	1.45E-04	1.81E-04	6.48E-05	1.57E-04	7.94E-04	2.33E-04	2.88E-04
(g/cm3)	variance	5.51E-06	9.05E-09	4.67E-09	3.57E-06	7.42E-09	5.70E-09	4.21E-07	8.48E-10	8.92E-10	1.06E-05	3.99E-09	4.45E-09	3.74E-09	7.45E-11	5.60E-11	7.49E-08	6.06E-10	1.87E-09	1.49E-09	6.33E-10	9.64E-10	6.61E-08	3.82E-10	7.95E-10
Olsen P (mg/l)	mean	4.65E-02	5.61E-02	5.76E-02	5.46E-02	5.45E-02	5.77E-02	2.34E-02	2.41E-02	2.50E-02	5.48E-02	5.51E-02	5.68E-02	3.54E-03	7.29E-03	6.89E-03	1.33E-02	1.71E-02	1.73E-02	2.66E-03	6.50E-03	5.99E-03	1.13E-02	1.45E-02	1.48E-02
t	variance	5.86E-04	1.36E-05	1.56E-05	9.58E-04	1.36E-05	1.71E-05	5.89E-05	2.48E-06	2.82E-06	9.51E-04	1.60E-05	1.59E-05	2.11E-07	2.19E-07	3.62E-07	1.02E-05	1.22E-06	1.43E-06	7.52E-08	1.71E-07	4.02E-07	6.23E-06	8.81E-07	1.07E-06
Total N (%)	mean	3.00E-02	3.02E-02	3.11E-02	2.95E-02	3.00E-02	3.12E-02	1.12E-02	1.31E-02	1.31E-02	2.65E-02	2.97E-02	3.13E-02	1.90E-03	3.85E-03	3.81E-03	7.21E-03	9.18E-03	9.31E-03	1.40E-03	3.48E-03	3.31E-03	5.94E-03	7.70E-03	8.07E-03
t	variance	3.36E-04	4.55E-06	1.31E-04	2.58E-04	4.19E-06	6.49E-05	1.78E-05	7.13E-07	1.70E-06	1.91E-04	5.26E-06	4.95E-06	7.54E-08	6.17E-08	1.22E-07	3.20E-06	3.44E-07	4.68E-07	2.47E-08	5.05E-08	3.17E-07	2.22E-06	2.79E-07	4.86E-07
Cu (mg/kg)	mean	2.94E-02	2.79E-02	2.94E-02	3.14E-02	2.67E-02	2.96E-02	1.24E-02	1.24E-02	1.26E-02	3.09E-02	2.91E-02	2.88E-02	1.98E-03	3.64E-03	3.42E-03	7.48E-03	9.50E-03	8.27E-03	1.49E-03	3.44E-03	3.04E-03	6.29E-03	7.28E-03	7.31E-03
t*	variance	2.45E-04	3.44E-06	4.85E-06	3.76E-04	3.36E-06	4.56E-06	2.56E-05	6.71E-07	8.01E-07	2.65E-04	3.84E-06	3.80E-06	1.43E-07	5.57E-08	1.00E-07	4.21E-06	3.70E-07	4.63E-07	4.78E-08	5.46E-08	6.43E-08	2.83E-06	2.35E-07	3.29E-07
Cd (mg/kg)	mean	3.53E-03	6.24E-03	7.73E-03	2.73E-03	6.35E-03	7.67E-03	1.29E-03	3.07E-03	3.10E-03	2.98E-03	6.52E-03	7.82E-03	2.19E-04	9.32E-04	8.61E-04	7.43E-04	2.25E-03	2.16E-03	1.52E-04	8.73E-04	7.22E-04	6.40E-04	1.89E-03	1.92E-03
t	variance	4.22E-06	2.02E-07	3.01E-07	2.93E-06	2.00E-07	2.92E-07	1.97E-07	4.06E-08	6.65E-08	4.54E-06	2.59E-07	2.76E-07	2.86E-09	3.75E-09	6.45E-09	5.21E-08	2.03E-08	2.78E-08	8.37E-10	3.30E-09	6.44E-09	2.40E-08	1.51E-08	2.05E-08
Zn (mg/kg)	mean	2.70E-02	2.61E-02	2.96E-02	2.69E-02	2.59E-02	2.84E-02	1.04E-02	1.16E-02	1.18E-02	2.75E-02	2.61E-02	2.74E-02	1.84E-03	3.50E-03	3.23E-03	6.88E-03	8.63E-03	7.99E-03	1.41E-03	3.16E-03	2.88E-03	5.72E-03	7.13E-03	6.90E-03
t	variance	2.60E-04	3.24E-06	3.73E-06	1.95E-04	3.06E-06	4.01E-06	1.29E-05	5.99E-07	7.74E-07	2.81E-04	3.37E-06	3.48E-06	8.07E-08	5.26E-08	7.57E-08	2.97E-06	3.07E-07	3.81E-07	4.86E-08	4.24E-08	6.98E-08	2.44E-06	2.15E-07	3.24E-07
Ni (mg/kg)	mean	3.92E-02	3.82E-02	3.78E-02	4.20E-02	3.72E-02	3.95E-02	1.52E-02	1.65E-02	1.66E-02	4.13E-02	3.99E-02	3.82E-02	2.57E-03	4.89E-03	4.73E-03	9.19E-03	1.20E-02	1.10E-02	1.86E-03	4.33E-03	4.20E-03	7.95E-03	9.63E-03	9.93E-03
t	variance	3.53E-04	6.46E-06	6.18E-06	6.12E-04	6.11E-06	7.15E-06	3.47E-05	1.19E-06	1.20E-06	6.33E-04	6.52E-06	6.34E-06	1.34E-07	1.03E-07	1.08E-07	6.41E-06	5.85E-07	6.27E-07	4.95E-08	8.75E-08	9.77E-08	4.53E-06	4.09E-07	4.45E-07
Mg (mg/l)	mean	4.37E-02	4.56E-02	4.86E-02	4.99E-02	4.24E-02	4.95E-02	2.10E-02	2.06E-02	2.15E-02	4.96E-02	4.67E-02	5.13E-02	3.53E-03	6.43E-03	5.74E-03	1.31E-02	1.51E-02	1.42E-02	2.55E-03	6.26E-03	5.01E-03	1.09E-02	1.25E-02	1.25E-02
t	variance	7.55E-04	1.00E-05	1.42E-05	9.03E-04	9.71E-06	1.37E-05	6.30E-05	1.90E-06	2.80E-06	1.01E-03	1.16E-05	1.26E-05	4.13E-07	1.73E-07	3.08E-07	1.66E-05	9.45E-07	1.50E-06	1.77E-07	1.64E-07	2.69E-07	5.73E-06	6.83E-07	9.28E-07
K (mg/l)	mean	3.30E-02	3.47E-02	3.40E-02	3.72E-02	3.32E-02	3.58E-02	1.35E-02	1.52E-02	1.51E-02	3.74E-02	3.59E-02	3.47E-02	2.25E-03	4.46E-03	4.27E-03	8.66E-03	1.07E-02	1.01E-02	1.70E-03	3.92E-03	3.82E-03	7.03E-03	9.06E-03	9.09E-03
t	variance	2.85E-04	5.29E-06	6.21E-06	5.41E-04	5.34E-06	5.75E-06	3.00E-05	9.80E-07	1.10E-06	5.43E-04	5.39E-06	6.18E-06	1.04E-07	8.26E-08	1.35E-07	3.79E-06	4.71E-07	5.43E-07	3.91E-08	6.59E-08	8.37E-08	2.64E-06	3.50E-07	4.31E-07
C/N	mean	5.22E-03	5.29E-03	5.24E-03	5.22E-03	5.31E-03	5.42E-03	2.01E-03	2.27E-03	2.29E-03	5.34E-03	5.31E-03	5.37E-03	3.30E-04	6.64E-04	6.59E-04	1.25E-03	1.59E-03	1.61E-03	2.49E-04	5.90E-04	5.78E-04	1.03E-03	1.38E-03	1.39E-03
t	variance	8.99E-06	1.38E-07	1.37E-05	1.05E-05	1.25E-07	3.68E-07	5.63E-07	2.14E-08	6.30E-08	1.12E-05	1.45E-07	2.00E-07	1.65E-09	2.21E-09	4.06E-08	1.16E-07	1.04E-08	1.19E-08	5.48E-10	1.46E-09	2.46E-09	6.05E-08	7.67E-09	1.34E-08
Change in	mean	3.51E+00	3.33E+00	3.67E+00	3.75E+00	3.37E+00	3.71E+00	1.68E+00	1.46E+00	1.52E+00	5.42E+00	3.31E+00	3.75E+00	1.92E-01	4.39E-01	4.40E-01	1.34E+00	1.04E+00	1.10E+00	9.10E-02	3.89E-01	3.84E-01	5.52E-01	8.88E-01	9.43E-01
SOC (%)	variance	3.55E+00	8.55E-02	1.94E-01	4.71E+00	9.20E-02	1.57E-01	2.76E-01	1.75E-02	3.08E-02	1.68E+01	8.86E-02	1.64E-01	7.24E-04	2.05E-03	2.68E-03	1.26E-01	1.03E-02	1.54E-02	2.86E-04	1.67E-03	2.23E-03	3.87E-02	7.45E-03	1.15E-02
Distance (km)		6.54E+03	6.17E+03	8.19E+03																					

Intensity S2

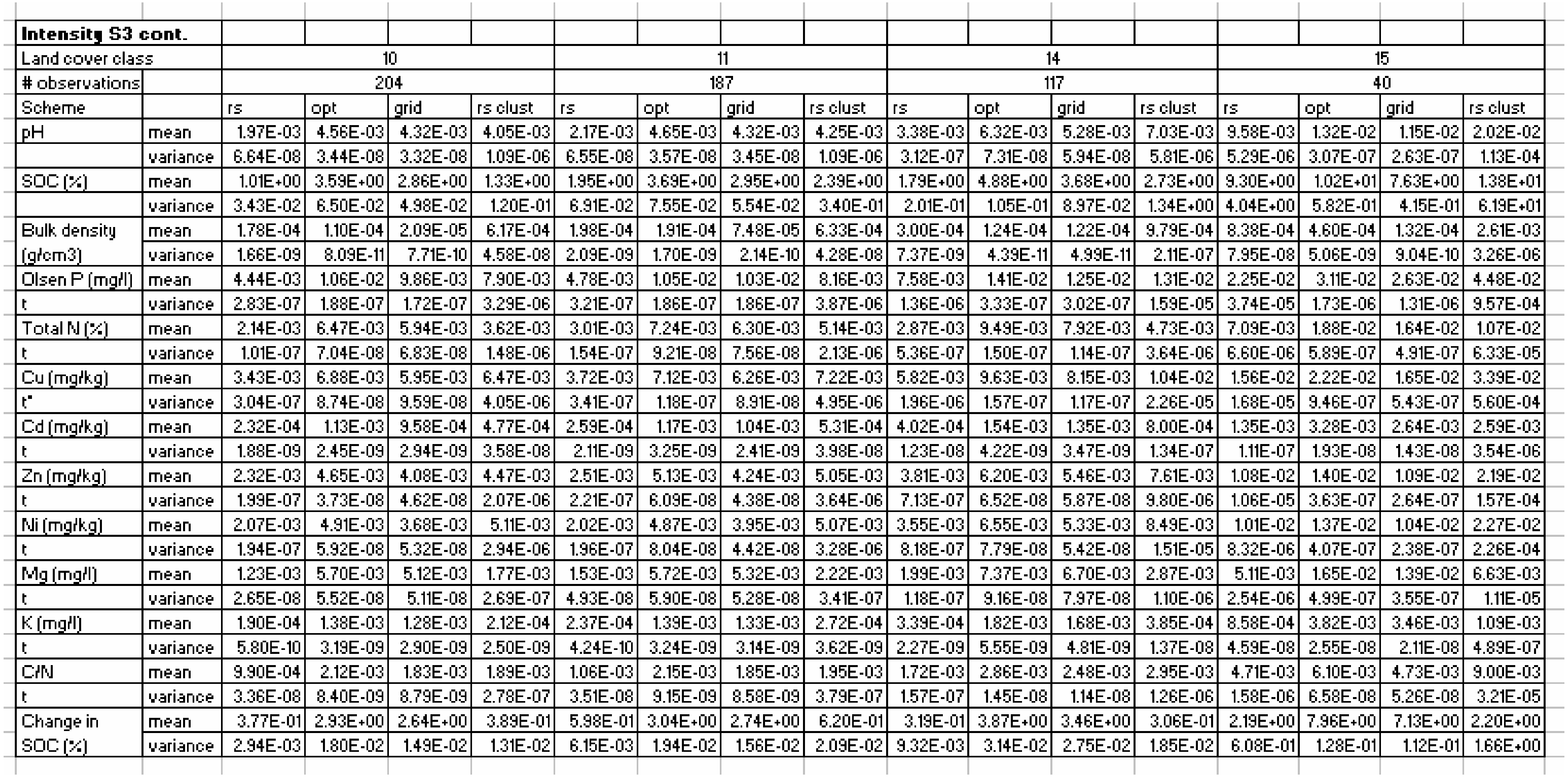
Intensity S2																									
Land cover class		5			6			8			9			10			11			14			15		
# observations		20			20			53			20			306			79			412			97		
Scheme		rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid
pH	mean	4.50E-02	5.37E-02	5.09E-02	4.63E-02	5.21E-02	5.12E-02	1.88E-02	2.29E-02	2.36E-02	4.68E-02	5.21E-02	5.23E-02	3.25E-03	9.47E-03	9.19E-03	1.23E-02	1.89E-02	1.78E-02	2.40E-03	8.73E-03	7.82E-03	1.01E-02	1.57E-02	1.52E-02
	variance	1.97E-04	5.89E-06	6.35E-06	3.15E-04	5.72E-06	6.16E-06	1.88E-05	1.15E-06	1.28E-06	2.76E-04	5.62E-06	5.70E-06	1.35E-07	2.01E-07	2.13E-07	5.56E-06	7.57E-07	7.40E-07	5.08E-08	1.86E-07	1.73E-07	2.93E-06	5.43E-07	5.56E-07
SOC (%)	mean	5.28E+00	3.10E+00	3.22E+00	6.63E+00	2.96E+00	3.29E+00	9.77E-01	1.38E+00	1.51E+00	4.07E+00	2.90E+00	3.29E+00	6.10E-02	5.69E-01	5.72E-01	6.98E-01	1.08E+00	1.12E+00	5.23E-02	5.22E-01	5.22E-01	3.37E-01	9.46E-01	9.69E-01
	variance	1.86E+01	4.41E-01	3.93E-01	2.88E+01	3.35E-01	4.66E-01	8.26E-01	8.34E-02	1.01E-01	1.29E+01	3.06E-01	4.68E-01	1.29E-03	1.88E-02	1.42E-02	2.43E-01	5.98E-02	5.37E-02	8.34E-04	1.58E-02	1.16E-02	8.33E-02	4.74E-02	4.01E-02
Bulk density (g/	mean	1.62E-03	6.85E-04	6.36E-04	1.70E-03	5.85E-04	6.05E-04	6.68E-04	1.85E-04	2.53E-04	1.77E-03	4.85E-04	4.88E-04	1.17E-04	1.09E-04	1.32E-04	4.39E-04	2.31E-04	2.20E-04	8.63E-05	4.57E-05	1.27E-05	3.49E-04	1.34E-04	1.52E-04
	variance	5.74E-07	8.10E-09	8.19E-09	6.53E-07	4.82E-09	5.13E-09	5.08E-08	2.24E-10	3.05E-10	4.97E-07	5.40E-10	5.50E-10	6.33E-10	1.10E-10	5.27E-10	1.80E-08	7.28E-10	1.13E-09	2.17E-10	2.89E-10	3.72E-10	6.74E-09	1.41E-10	7.00E-11
Olsen P (mg/l)	mean	2.75E-02	3.05E-02	2.83E-02	2.56E-02	2.82E-02	2.91E-02	1.05E-02	1.36E-02	1.35E-02	2.80E-02	2.91E-02	2.97E-02	1.79E-03	5.54E-03	5.10E-03	6.76E-03	1.08E-02	1.00E-02	1.35E-03	5.07E-03	4.65E-03	5.69E-03	9.13E-03	8.66E-03
t	variance	6.90E-05	1.90E-06	4.09E-06	8.25E-05	1.78E-06	2.27E-06	6.31E-06	3.79E-07	5.17E-07	1.07E-04	1.92E-06	2.44E-06	2.77E-08	6.80E-08	8.99E-08	1.44E-06	2.44E-07	2.89E-07	1.35E-08	5.64E-08	6.98E-08	9.06E-07	1.77E-07	2.67E-07
Total N (%)	mean	1.32E-02	1.56E-02	1.54E-02	1.40E-02	1.48E-02	1.63E-02	5.55E-03	7.08E-03	7.47E-03	1.46E-02	1.45E-02	1.62E-02	9.62E-04	3.00E-03	2.78E-03	3.62E-03	5.56E-03	5.60E-03	6.95E-04	2.74E-03	2.58E-03	3.03E-03	4.90E-03	4.90E-03
t	variance	2.35E-05	5.26E-07	1.79E-05	1.92E-05	6.70E-07	2.17E-06	1.58E-06	1.14E-07	2.39E-07	2.51E-05	7.28E-07	1.85E-06	8.71E-09	1.94E-08	2.96E-07	3.64E-07	6.30E-08	1.02E-07	4.03E-09	1.59E-08	4.62E-08	1.64E-07	4.86E-08	4.19E-07
Cu (mg/kg)	mean	1.41E-02	1.52E-02	1.40E-02	1.45E-02	1.38E-02	1.42E-02	5.88E-03	6.47E-03	6.77E-03	1.77E-02	1.46E-02	1.44E-02	9.99E-04	2.83E-03	2.57E-03	3.86E-03	5.55E-03	5.00E-03	7.69E-04	2.56E-03	2.23E-03	3.20E-03	4.80E-03	4.11E-03
t"	variance	2.31E-05	4.66E-07	6.67E-07	3.05E-05	4.40E-07	5.89E-07	2.43E-06	8.96E-08	1.12E-07	6.57E-05	4.69E-07	6.54E-07	1.88E-08	1.80E-08	2.09E-08	5.93E-07	6.88E-08	7.86E-08	1.40E-08	1.80E-08	2.27E-08	2.34E-07	5.05E-08	5.89E-08
Cd (mg/kg)	mean	1.65E-03	3.74E-03	3.35E-03	1.47E-03	3.23E-03	3.30E-03	5.79E-04	1.59E-03	1.61E-03	1.48E-03	3.15E-03	3.53E-03	1.07E-04	7.23E-04	5.88E-04	3.93E-04	1.40E-03	1.18E-03	7.46E-05	6.89E-04	5.33E-04	3.25E-04	1.13E-03	1.02E-03
t	variance	4.98E-07	2.75E-08	6.61E-08	3.01E-07	2.29E-08	5.40E-08	2.22E-08	5.30E-09	1.01E-08	2.86E-07	2.60E-08	6.93E-08	3.56E-10	1.17E-09	2.18E-09	6.91E-09	4.03E-09	7.79E-09	1.06E-10	1.12E-09	2.14E-09	3.83E-09	2.60E-09	5.10E-09
Zn (mg/kg)	mean	1.31E-02	1.47E-02	1.35E-02	1.44E-02	1.35E-02	1.34E-02	5.29E-03	6.56E-03	6.42E-03	1.41E-02	1.34E-02	1.38E-02	9.37E-04	2.76E-03	2.49E-03	3.57E-03	5.20E-03	4.61E-03	6.88E-04	2.45E-03	2.10E-03	2.87E-03	4.51E-03	4.03E-03
t	variance	1.74E-05	4.33E-07	6.63E-07	2.46E-05	3.99E-07	6.54E-07	1.57E-06	8.84E-08	1.06E-07	2.35E-05	4.31E-07	5.66E-07	1.49E-08	1.81E-08	2.01E-08	4.81E-07	5.72E-08	7.04E-08	5.36E-09	1.35E-08	1.92E-08	2.91E-07	4.40E-08	5.73E-08
Ni (mg/kg)	mean	1.80E-02	2.04E-02	1.97E-02	1.90E-02	1.98E-02	2.01E-02	7.15E-03	8.94E-03	9.12E-03	1.88E-02	1.98E-02	2.00E-02	1.26E-03	3.71E-03	3.57E-03	4.68E-03	7.20E-03	6.82E-03	9.37E-04	3.34E-03	3.03E-03	3.91E-03	6.13E-03	5.79E-03
t	variance	4.71E-05	8.73E-07	1.01E-06	4.57E-05	8.36E-07	8.64E-07	2.29E-06	1.74E-07	1.90E-07	4.49E-05	8.23E-07	9.16E-07	2.17E-08	2.91E-08	3.38E-08	7.05E-07	1.06E-07	1.15E-07	1.22E-08	2.83E-08	2.74E-08	4.67E-07	8.26E-08	8.65E-08
Mg (mg/l)	mean	2.57E-02	2.68E-02	2.26E-02	2.61E-02	2.27E-02	2.37E-02	1.02E-02	1.08E-02	1.12E-02	2.75E-02	2.26E-02	2.37E-02	1.79E-03	5.05E-03	4.14E-03	6.74E-03	9.31E-03	7.87E-03	1.31E-03	4.25E-03	3.60E-03	5.63E-03	8.04E-03	7.08E-03
t	variance	7.71E-05	1.46E-06	3.55E-06	1.11E-04	1.13E-06	1.98E-06	6.65E-06	2.47E-07	3.77E-07	1.04E-04	1.26E-06	2.37E-06	7.78E-08	5.86E-08	8.93E-08	1.96E-06	1.80E-07	2.48E-07	3.07E-08	4.17E-08	8.58E-08	1.20E-06	1.42E-07	2.39E-07
K (mg/l)	mean	1.70E-02	1.88E-02	1.77E-02	1.76E-02	1.81E-02	1.79E-02	6.66E-03	8.36E-03	8.45E-03	1.74E-02	1.79E-02	1.79E-02	1.14E-03	3.38E-03	3.20E-03	4.24E-03	6.58E-03	6.16E-03	8.53E-04	3.11E-03	2.80E-03	3.58E-03	5.83E-03	5.30E-03
t	variance	2.77E-05	7.13E-07	9.28E-07	4.36E-05	6.92E-07	9.47E-07	2.24E-06	1.45E-07	1.61E-07	3.21E-05	6.97E-07	8.40E-07	1.52E-08	2.52E-08	2.78E-08	5.50E-07	9.22E-08	9.98E-08	6.36E-09	2.27E-08	2.57E-08	3.05E-07	7.37E-08	7.73E-08
C/N	mean	2.33E-03	2.76E-03	2.74E-03	2.51E-03	2.77E-03	2.85E-03	9.54E-04	1.25E-03	1.29E-03	2.69E-03	2.72E-03	2.83E-03	1.66E-04	5.10E-04	4.94E-04	6.49E-04	9.71E-04	9.64E-04	1.22E-04	4.69E-04	4.51E-04	5.31E-04	8.43E-04	8.40E-04
t	variance	6.77E-07	1.92E-08	5.99E-07	6.03E-07	1.95E-08	4.07E-08	4.09E-08	3.58E-09	3.44E-07	8.03E-07	2.23E-08	3.28E-08	2.22E-10	5.71E-10	5.46E-09	1.47E-08	1.89E-09	7.85E-09	8.23E-11	4.67E-10	7.72E-10	7.46E-09	1.46E-09	2.40E-08
Change in SOC	mean	1.62E+00	2.18E+00	1.95E+00	1.94E+00	2.17E+00	1.95E+00	7.94E-01	9.80E-01	8.89E-01	2.30E+00	2.17E+00	1.95E+00	9.74E-02	3.82E-01	3.40E-01	6.65E-01	7.43E-01	6.63E-01	4.46E-02	3.49E-01	3.10E-01	2.72E-01	6.47E-01	5.75E-01
	variance	3.24E-01	2.75E-02	2.98E-02	5.44E-01	2.91E-02	2.99E-02	5.58E-02	5.72E-03	6.24E-03	6.97E-01	2.83E-02	2.99E-02	9.95E-05	8.76E-04	9.12E-04	1.79E-02	3.21E-03	3.47E-03	2.98E-05	7.34E-04	7.60E-04	2.55E-03	2.46E-03	2.61E-03
Distance (km)		9.49E+03	7.90E+03	1.19E+04																					

Intensity S3



Intensity S3																					
Land cover class		5				6				7				8				9			
# observations		58				357				67				40				150			
Scheme		rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust
pH	mean	6.85E-03	1.01E-02	8.84E-03	1.39E-02	1.13E-03	3.76E-03	3.46E-03	2.34E-03	6.01E-03	8.82E-03	7.90E-03	1.17E-02	1.05E-02	1.13E-02	1.17E-02	2.02E-02	2.73E-03	5.12E-03	4.81E-03	5.67E-03
	variance	1.85E-06	2.19E-07	1.38E-07	3.84E-05	1.40E-08	2.38E-08	2.17E-08	3.01E-07	1.26E-06	1.43E-07	1.14E-07	2.38E-05	5.57E-06	2.57E-07	2.56E-07	1.83E-04	1.64E-07	4.33E-08	4.29E-08	2.03E-06
SOC (%)	mean	8.82E+00	7.92E+00	6.01E+00	1.02E+01	1.04E+00	2.99E+00	2.37E+00	1.18E+00	5.57E+00	7.01E+00	5.34E+00	6.61E+00	8.99E+00	8.66E+00	7.76E+00	1.31E+01	2.70E+00	4.04E+00	3.32E+00	3.40E+00
	variance	1.44E+00	4.05E-01	2.42E-01	1.93E+01	8.40E-03	3.89E-02	3.50E-02	3.84E-02	6.65E-01	2.73E-01	1.99E-01	5.60E+00	4.32E+00	8.24E-01	4.39E-01	8.71E+01	9.24E-02	8.80E-02	6.19E-02	6.43E-01
Bulk density (g/cm3)	mean	5.67E-04	3.36E-04	2.95E-04	1.79E-03	1.06E-04	1.73E-04	1.20E-04	3.53E-04	5.32E-04	4.20E-04	4.43E-04	1.69E-03	9.46E-04	3.40E-04	1.80E-04	3.77E-03	2.40E-04	1.40E-04	1.00E-04	7.84E-04
	variance	2.79E-08	1.79E-09	1.70E-09	9.28E-07	4.99E-10	1.70E-09	5.08E-10	1.19E-08	3.48E-08	7.14E-09	9.34E-09	1.03E-06	7.40E-08	1.68E-09	5.36E-10	8.98E-06	2.99E-09	3.06E-10	1.24E-10	9.58E-08
Olsen P (mg/l)	mean	1.54E-02	2.31E-02	2.07E-02	2.40E-02	2.54E-03	8.45E-03	8.16E-03	4.49E-03	1.31E-02	2.08E-02	1.78E-02	2.27E-02	2.32E-02	2.63E-02	2.65E-02	3.98E-02	5.93E-03	1.19E-02	1.11E-02	1.07E-02
t	variance	1.15E-05	1.01E-06	7.24E-07	1.29E-04	4.97E-08	1.21E-07	1.19E-07	7.63E-07	6.37E-06	7.87E-07	6.02E-07	9.14E-05	3.28E-05	1.34E-06	1.40E-06	5.36E-04	5.40E-07	2.38E-07	2.29E-07	7.21E-06
Total N (%)	mean	1.00E-02	1.49E-02	1.26E-02	1.61E-02	1.60E-03	5.30E-03	5.18E-03	2.83E-03	7.96E-03	1.25E-02	1.14E-02	1.35E-02	1.20E-02	1.65E-02	1.68E-02	2.18E-02	3.66E-03	7.40E-03	6.93E-03	6.19E-03
t	variance	3.98E-06	3.88E-07	2.82E-07	7.00E-05	2.93E-08	4.93E-08	4.78E-08	5.53E-07	1.57E-06	2.66E-07	2.39E-07	3.54E-05	8.04E-06	4.89E-07	5.02E-07	1.71E-04	3.05E-07	9.40E-08	8.70E-08	3.59E-06
Cu (mg/kg)	mean	1.13E-02	1.62E-02	1.36E-02	2.21E-02	1.95E-03	6.02E-03	5.32E-03	3.79E-03	9.81E-03	1.38E-02	1.24E-02	1.76E-02	1.67E-02	1.73E-02	1.68E-02	2.93E-02	4.45E-03	7.74E-03	7.26E-03	8.52E-03
t*	variance	9.22E-06	4.85E-07	3.38E-07	1.51E-04	9.90E-08	8.79E-08	6.16E-08	1.89E-06	6.04E-06	4.11E-07	3.66E-07	7.45E-05	1.63E-05	5.44E-07	5.50E-07	2.89E-04	5.66E-07	1.12E-07	9.93E-08	8.06E-06
Cd (mg/kg)	mean	7.05E-04	2.77E-03	2.15E-03	1.30E-03	1.27E-04	9.68E-04	8.80E-04	2.62E-04	6.98E-04	2.26E-03	2.04E-03	1.22E-03	1.06E-03	2.81E-03	2.76E-03	2.26E-03	2.90E-04	1.33E-03	1.21E-03	5.76E-04
t	variance	2.79E-08	1.46E-08	8.55E-09	3.90E-07	6.44E-10	2.22E-09	1.66E-09	9.67E-09	4.69E-08	1.08E-08	1.09E-08	3.31E-07	9.61E-08	1.45E-08	1.46E-08	3.27E-06	3.86E-09	3.00E-09	2.62E-09	5.70E-08
Zn (mg/kg)	mean	7.60E-03	1.14E-02	9.17E-03	1.52E-02	1.33E-03	4.08E-03	3.70E-03	2.66E-03	6.70E-03	9.52E-03	8.27E-03	1.20E-02	1.11E-02	1.20E-02	1.15E-02	2.12E-02	3.12E-03	5.47E-03	4.87E-03	6.18E-03
t	variance	4.22E-06	2.40E-07	1.66E-07	6.20E-05	5.53E-08	4.35E-08	2.99E-08	9.34E-07	3.84E-06	1.91E-07	1.75E-07	3.46E-05	1.11E-05	2.52E-07	2.49E-07	2.69E-04	4.03E-07	5.28E-08	4.54E-08	6.28E-06
Ni (mg/kg)	mean	4.70E-03	1.04E-02	8.93E-03	1.13E-02	8.92E-04	3.73E-03	3.48E-03	2.20E-03	4.48E-03	1.00E-02	8.30E-03	1.08E-02	8.80E-03	1.11E-02	1.05E-02	2.29E-02	2.19E-03	4.97E-03	4.70E-03	5.43E-03
t	variance	1.59E-06	1.96E-07	1.47E-07	4.22E-05	4.09E-08	4.37E-08	4.06E-08	5.62E-07	1.37E-06	2.71E-07	2.23E-07	5.70E-05	6.38E-06	2.23E-07	2.34E-07	2.66E-04	2.21E-07	5.18E-08	3.98E-08	4.66E-06
Mg (mg/l)	mean	6.45E-03	1.26E-02	1.09E-02	9.48E-03	9.46E-04	4.61E-03	4.32E-03	1.36E-03	4.04E-03	1.06E-02	9.84E-03	5.51E-03	6.44E-03	1.45E-02	1.41E-02	1.04E-02	1.88E-03	6.13E-03	5.84E-03	2.69E-03
t	variance	1.42E-06	3.08E-07	1.99E-07	2.52E-05	9.35E-09	3.92E-08	3.38E-08	1.10E-07	5.89E-07	1.93E-07	1.74E-07	5.78E-06	2.99E-06	3.50E-07	3.53E-07	3.63E-05	6.80E-08	6.30E-08	6.24E-08	6.71E-07
K (mg/l)	mean	8.28E-04	2.90E-03	2.64E-03	9.22E-04	1.41E-04	1.09E-03	1.06E-03	1.62E-04	6.65E-04	2.53E-03	2.40E-03	7.17E-04	1.09E-03	3.49E-03	3.51E-03	1.22E-03	3.00E-04	1.51E-03	1.49E-03	3.26E-04
t	variance	2.60E-08	1.47E-08	1.19E-08	1.69E-07	1.57E-10	1.95E-09	1.84E-09	7.71E-10	1.32E-08	1.05E-08	9.62E-09	8.90E-08	5.49E-08	2.11E-08	2.08E-08	4.19E-07	1.38E-09	3.73E-09	3.67E-09	7.76E-09
C/N	mean	3.40E-03	4.84E-03	4.06E-03	6.52E-03	5.82E-04	1.76E-03	1.61E-03	1.08E-03	2.92E-03	4.27E-03	3.73E-03	4.68E-03	4.89E-03	5.28E-03	5.13E-03	1.00E-02	1.34E-03	2.40E-03	2.20E-03	2.50E-03
t	variance	6.92E-07	4.19E-08	2.95E-08	1.27E-05	1.03E-08	7.52E-09	5.46E-09	9.29E-08	4.45E-07	3.55E-08	3.35E-08	3.84E-06	1.58E-06	4.81E-08	4.96E-08	4.43E-05	4.83E-08	1.04E-08	8.70E-09	8.28E-07
Change in SOC (%)	mean	1.07E+00	6.08E+00	5.48E+00	1.08E+00	3.73E-01	2.40E+00	2.16E+00	3.74E-01	NA	NA	NA	NA	2.64E+00	8.00E+00	7.24E+00	2.56E+00	1.01E+00	3.38E+00	3.05E+00	1.14E+00
	variance	7.84E-02	7.95E-02	6.96E-02	2.89E-01	1.42E-03	1.18E-02	1.00E-02	3.95E-03	NA	NA	NA	NA	7.64E-01	1.23E-01	1.12E-01	2.37E+00	3.01E-02	2.26E-02	1.96E-02	8.60E-02
Distance (km)		8.91E+03	8.18E+03	9.83E+03	4.83E+03																

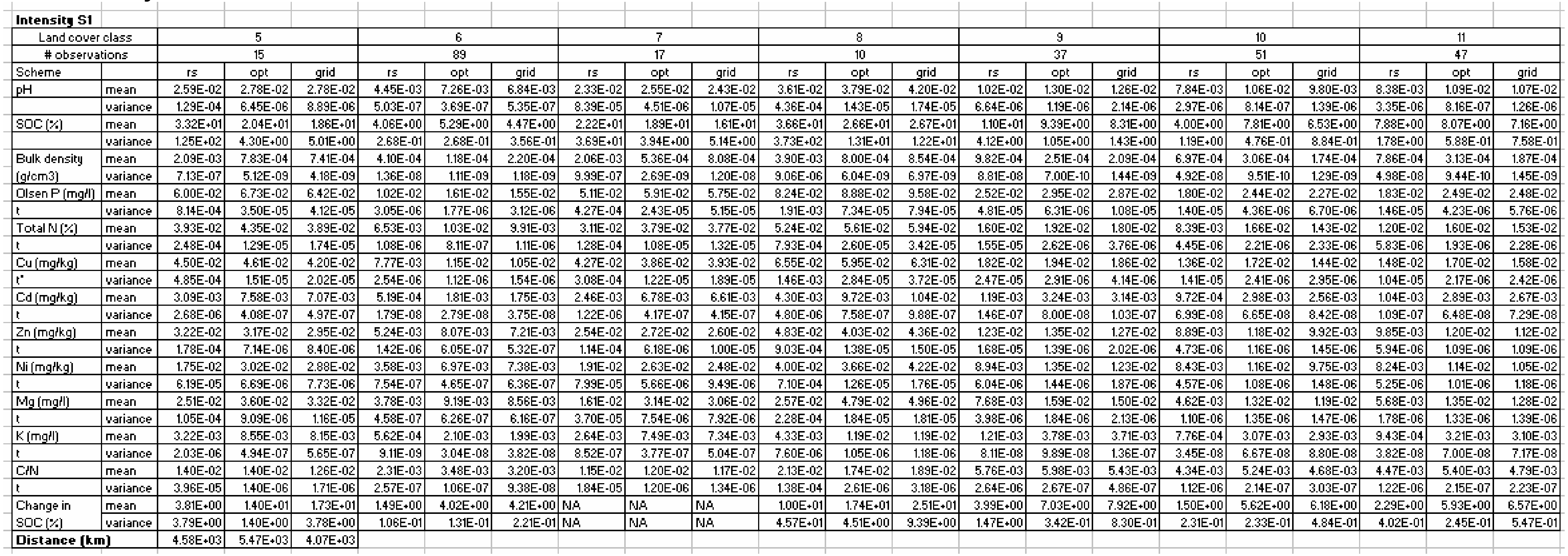
Intensity S3 cont.



Intensity S3 cont.																
Land cover class		10				11				14				15		
# observations		204				187				117				40		
Scheme		rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust
pH	mean	1.97E-03	4.56E-03	4.32E-03	4.05E-03	2.17E-03	4.65E-03	4.32E-03	4.25E-03	3.38E-03	6.32E-03	5.28E-03	7.03E-03	9.58E-03	1.32E-02	1.15E-02	2.02E-02
	variance	6.64E-08	3.44E-08	3.32E-08	1.09E-06	6.55E-08	3.57E-08	3.45E-08	1.09E-06	3.12E-07	7.31E-08	5.94E-08	5.81E-06	5.29E-06	3.07E-07	2.63E-07	1.13E-04
SOC (%)	mean	1.01E+00	3.59E+00	2.86E+00	1.33E+00	1.95E+00	3.69E+00	2.95E+00	2.39E+00	1.79E+00	4.88E+00	3.68E+00	2.73E+00	9.30E+00	1.02E+01	7.63E+00	1.38E+01
	variance	3.43E-02	6.50E-02	4.98E-02	1.20E-01	6.91E-02	7.55E-02	5.54E-02	3.40E-01	2.01E-01	1.05E-01	8.97E-02	1.34E+00	4.04E+00	5.82E-01	4.15E-01	6.19E+01
Bulk density (g/cm3)	mean	1.78E-04	1.10E-04	2.09E-05	6.17E-04	1.98E-04	1.91E-04	7.48E-05	6.33E-04	3.00E-04	1.24E-04	1.22E-04	9.79E-04	8.38E-04	4.60E-04	1.32E-04	2.61E-03
	variance	1.66E-09	8.09E-11	7.71E-10	4.58E-08	2.09E-09	1.70E-09	2.14E-10	4.28E-08	7.37E-09	4.39E-11	4.99E-11	2.11E-07	7.95E-08	5.06E-09	9.04E-10	3.26E-06
Olsen P (mg/l)	mean	4.44E-03	1.06E-02	9.86E-03	7.90E-03	4.78E-03	1.05E-02	1.03E-02	8.16E-03	7.58E-03	1.41E-02	1.25E-02	1.31E-02	2.25E-02	3.11E-02	2.63E-02	4.48E-02
t	variance	2.83E-07	1.88E-07	1.72E-07	3.29E-06	3.21E-07	1.86E-07	1.86E-07	3.87E-06	1.36E-06	3.33E-07	3.02E-07	1.59E-05	3.74E-05	1.73E-06	1.31E-06	9.57E-04
Total N (%)	mean	2.14E-03	6.47E-03	5.94E-03	3.62E-03	3.01E-03	7.24E-03	6.30E-03	5.14E-03	2.87E-03	9.49E-03	7.92E-03	4.73E-03	7.09E-03	1.88E-02	1.64E-02	1.07E-02
t	variance	1.01E-07	7.04E-08	6.83E-08	1.48E-06	1.54E-07	9.21E-08	7.56E-08	2.13E-06	5.36E-07	1.50E-07	1.14E-07	3.64E-06	6.60E-06	5.89E-07	4.91E-07	6.33E-05
Cu (mg/kg)	mean	3.43E-03	6.88E-03	5.95E-03	6.47E-03	3.72E-03	7.12E-03	6.26E-03	7.22E-03	5.82E-03	9.63E-03	8.15E-03	1.04E-02	1.56E-02	2.22E-02	1.65E-02	3.39E-02
t"	variance	3.04E-07	8.74E-08	9.59E-08	4.05E-06	3.41E-07	1.18E-07	8.91E-08	4.95E-06	1.96E-06	1.57E-07	1.17E-07	2.26E-05	1.68E-05	9.46E-07	5.43E-07	5.60E-04
Cd (mg/kg)	mean	2.32E-04	1.13E-03	9.58E-04	4.77E-04	2.59E-04	1.17E-03	1.04E-03	5.31E-04	4.02E-04	1.54E-03	1.35E-03	8.00E-04	1.35E-03	3.28E-03	2.64E-03	2.59E-03
t	variance	1.88E-09	2.45E-09	2.94E-09	3.58E-08	2.11E-09	3.25E-09	2.41E-09	3.98E-08	1.23E-08	4.22E-09	3.47E-09	1.34E-07	1.11E-07	1.93E-08	1.43E-08	3.54E-06
Zn (mg/kg)	mean	2.32E-03	4.65E-03	4.08E-03	4.47E-03	2.51E-03	5.13E-03	4.24E-03	5.05E-03	3.81E-03	6.20E-03	5.46E-03	7.61E-03	1.08E-02	1.40E-02	1.09E-02	2.19E-02
t	variance	1.99E-07	3.73E-08	4.62E-08	2.07E-06	2.21E-07	6.09E-08	4.38E-08	3.64E-06	7.13E-07	6.52E-08	5.87E-08	9.80E-06	1.06E-05	3.63E-07	2.64E-07	1.57E-04
Ni (mg/kg)	mean	2.07E-03	4.91E-03	3.68E-03	5.11E-03	2.02E-03	4.87E-03	3.95E-03	5.07E-03	3.55E-03	6.55E-03	5.33E-03	8.49E-03	1.01E-02	1.37E-02	1.04E-02	2.27E-02
t	variance	1.94E-07	5.92E-08	5.32E-08	2.94E-06	1.96E-07	8.04E-08	4.42E-08	3.28E-06	8.18E-07	7.79E-08	5.42E-08	1.51E-05	8.32E-06	4.07E-07	2.38E-07	2.26E-04
Mg (mg/l)	mean	1.23E-03	5.70E-03	5.12E-03	1.77E-03	1.53E-03	5.72E-03	5.32E-03	2.22E-03	1.99E-03	7.37E-03	6.70E-03	2.87E-03	5.11E-03	1.65E-02	1.39E-02	6.63E-03
t	variance	2.65E-08	5.52E-08	5.11E-08	2.69E-07	4.93E-08	5.90E-08	5.28E-08	3.41E-07	1.18E-07	9.16E-08	7.97E-08	1.10E-06	2.54E-06	4.99E-07	3.55E-07	1.11E-05
K (mg/l)	mean	1.90E-04	1.38E-03	1.28E-03	2.12E-04	2.37E-04	1.39E-03	1.33E-03	2.72E-04	3.39E-04	1.82E-03	1.68E-03	3.85E-04	8.58E-04	3.82E-03	3.46E-03	1.09E-03
t	variance	5.80E-10	3.19E-09	2.90E-09	2.50E-09	4.24E-10	3.24E-09	3.14E-09	3.62E-09	2.27E-09	5.55E-09	4.81E-09	1.37E-08	4.59E-08	2.55E-08	2.11E-08	4.89E-07
C/N	mean	9.90E-04	2.12E-03	1.83E-03	1.89E-03	1.06E-03	2.15E-03	1.85E-03	1.95E-03	1.72E-03	2.86E-03	2.48E-03	2.95E-03	4.71E-03	6.10E-03	4.73E-03	9.00E-03
t	variance	3.36E-08	8.40E-09	8.79E-09	2.78E-07	3.51E-08	9.15E-09	8.58E-09	3.79E-07	1.57E-07	1.45E-08	1.14E-08	1.26E-06	1.58E-06	6.58E-08	5.26E-08	3.21E-05
Change in SOC (%)	mean	3.77E-01	2.93E+00	2.64E+00	3.89E-01	5.98E-01	3.04E+00	2.74E+00	6.20E-01	3.19E-01	3.87E+00	3.46E+00	3.06E-01	2.19E+00	7.96E+00	7.13E+00	2.20E+00
	variance	2.94E-03	1.80E-02	1.49E-02	1.31E-02	6.15E-03	1.94E-02	1.56E-02	2.09E-02	9.32E-03	3.14E-02	2.75E-02	1.85E-02	6.08E-01	1.28E-01	1.12E-01	1.66E+00

Scotland

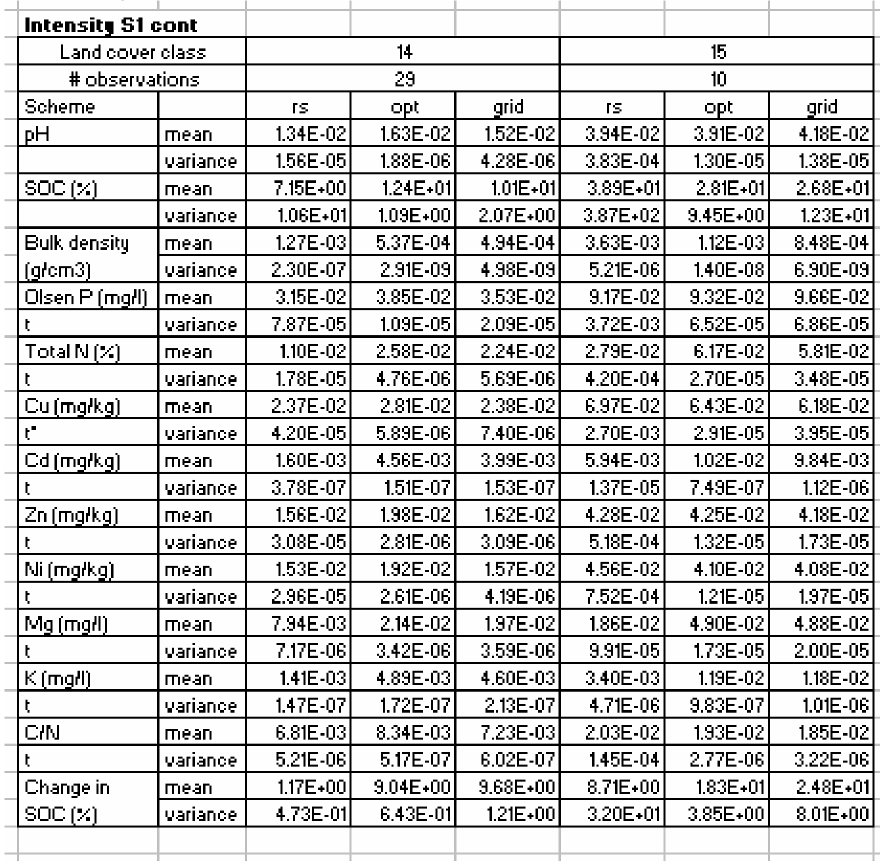
Intensity S1



Intensity S1

Land cover class		5			6			7			8			9			10			11		
# observations		15			89			17			10			37			51			47		
Scheme		rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid
pH	mean	2.59E-02	2.78E-02	2.78E-02	4.45E-03	7.26E-03	6.84E-03	2.33E-02	2.55E-02	2.43E-02	3.61E-02	3.79E-02	4.20E-02	1.02E-02	1.30E-02	1.26E-02	7.84E-03	1.06E-02	9.80E-03	8.38E-03	1.09E-02	1.07E-02
	variance	1.29E-04	6.45E-06	8.89E-06	5.03E-07	3.69E-07	5.35E-07	8.39E-05	4.51E-06	1.07E-05	4.36E-04	1.43E-05	1.74E-05	6.64E-06	1.19E-06	2.14E-06	2.97E-06	8.14E-07	1.39E-06	3.35E-06	8.16E-07	1.26E-06
SOC (%)	mean	3.32E+01	2.04E+01	1.86E+01	4.06E+00	5.29E+00	4.47E+00	2.22E+01	1.89E+01	1.61E+01	3.66E+01	2.66E+01	2.67E+01	1.10E+01	9.39E+00	8.31E+00	4.00E+00	7.81E+00	6.53E+00	7.88E+00	8.07E+00	7.16E+00
	variance	1.25E+02	4.30E+00	5.01E+00	2.68E-01	2.68E-01	3.56E-01	3.69E+01	3.94E+00	5.14E+00	3.73E+02	1.31E+01	1.22E+01	4.12E+00	1.05E+00	1.43E+00	1.19E+00	4.76E-01	8.84E-01	1.78E+00	5.88E-01	7.58E-01
Bulk density	mean	2.09E-03	7.83E-04	7.41E-04	4.10E-04	1.18E-04	2.20E-04	2.06E-03	5.36E-04	8.08E-04	3.90E-03	8.00E-04	8.54E-04	9.82E-04	2.51E-04	2.09E-04	6.97E-04	3.06E-04	1.74E-04	7.86E-04	3.13E-04	1.87E-04
(g/cm3)	variance	7.13E-07	5.12E-09	4.18E-09	1.36E-08	1.11E-09	1.18E-09	9.99E-07	2.69E-09	1.20E-08	9.06E-06	6.04E-09	6.97E-09	8.81E-08	7.00E-10	1.44E-09	4.92E-08	9.51E-10	1.29E-09	4.98E-08	9.44E-10	1.45E-09
Olsen P (mg/l)	mean	6.00E-02	6.73E-02	6.42E-02	1.02E-02	1.61E-02	1.55E-02	5.11E-02	5.91E-02	5.75E-02	8.24E-02	8.88E-02	9.58E-02	2.52E-02	2.95E-02	2.87E-02	1.80E-02	2.44E-02	2.27E-02	1.83E-02	2.49E-02	2.48E-02
t	variance	8.14E-04	3.50E-05	4.12E-05	3.05E-06	1.77E-06	3.12E-06	4.27E-04	2.43E-05	5.15E-05	1.91E-03	7.34E-05	7.94E-05	4.81E-05	6.31E-06	1.08E-05	1.40E-05	4.36E-06	6.70E-06	1.46E-05	4.23E-06	5.76E-06
Total N (%)	mean	3.93E-02	4.35E-02	3.89E-02	6.53E-03	1.03E-02	9.91E-03	3.11E-02	3.79E-02	3.77E-02	5.24E-02	5.61E-02	5.94E-02	1.60E-02	1.92E-02	1.80E-02	8.39E-03	1.66E-02	1.43E-02	1.20E-02	1.60E-02	1.53E-02
t	variance	2.48E-04	1.29E-05	1.74E-05	1.08E-06	8.11E-07	1.11E-06	1.28E-04	1.08E-05	1.32E-05	7.93E-04	2.60E-05	3.42E-05	1.55E-05	2.62E-06	3.76E-06	4.45E-06	2.21E-06	2.33E-06	5.83E-06	1.93E-06	2.28E-06
Cu (mg/kg)	mean	4.50E-02	4.61E-02	4.20E-02	7.77E-03	1.15E-02	1.05E-02	4.27E-02	3.86E-02	3.93E-02	6.55E-02	5.95E-02	6.31E-02	1.82E-02	1.94E-02	1.86E-02	1.36E-02	1.72E-02	1.44E-02	1.48E-02	1.70E-02	1.58E-02
t*	variance	4.85E-04	1.51E-05	2.02E-05	2.54E-06	1.12E-06	1.54E-06	3.08E-04	1.22E-05	1.89E-05	1.46E-03	2.84E-05	3.72E-05	2.47E-05	2.91E-06	4.14E-06	1.41E-05	2.41E-06	2.95E-06	1.04E-05	2.17E-06	2.42E-06
Cd (mg/kg)	mean	3.09E-03	7.58E-03	7.07E-03	5.19E-04	1.81E-03	1.75E-03	2.46E-03	6.78E-03	6.61E-03	4.30E-03	9.72E-03	1.04E-02	1.19E-03	3.24E-03	3.14E-03	9.72E-04	2.98E-03	2.56E-03	1.04E-03	2.89E-03	2.67E-03
t	variance	2.68E-06	4.08E-07	4.97E-07	1.79E-08	2.79E-08	3.75E-08	1.22E-06	4.17E-07	4.15E-07	4.80E-06	7.58E-07	9.88E-07	1.46E-07	8.00E-08	1.03E-07	6.99E-08	6.65E-08	8.42E-08	1.09E-07	6.48E-08	7.29E-08
Zn (mg/kg)	mean	3.22E-02	3.17E-02	2.95E-02	5.24E-03	8.07E-03	7.21E-03	2.54E-02	2.72E-02	2.60E-02	4.83E-02	4.03E-02	4.36E-02	1.23E-02	1.35E-02	1.27E-02	8.89E-03	1.18E-02	9.92E-03	9.85E-03	1.20E-02	1.12E-02
t	variance	1.78E-04	7.14E-06	8.40E-06	1.42E-06	6.05E-07	5.32E-07	1.14E-04	6.18E-06	1.00E-05	9.03E-04	1.38E-05	1.50E-05	1.68E-05	1.39E-06	2.02E-06	4.73E-06	1.16E-06	1.45E-06	5.94E-06	1.09E-06	1.09E-06
Ni (mg/kg)	mean	1.75E-02	3.02E-02	2.88E-02	3.58E-03	6.97E-03	7.38E-03	1.91E-02	2.63E-02	2.48E-02	4.00E-02	3.66E-02	4.22E-02	8.94E-03	1.35E-02	1.23E-02	8.43E-03	1.16E-02	9.75E-03	8.24E-03	1.14E-02	1.05E-02
t	variance	6.19E-05	6.69E-06	7.73E-06	7.54E-07	4.65E-07	6.36E-07	7.99E-05	5.66E-06	9.49E-06	7.10E-04	1.26E-05	1.76E-05	6.04E-06	1.44E-06	1.87E-06	4.57E-06	1.08E-06	1.48E-06	5.25E-06	1.01E-06	1.18E-06
Mg (mg/l)	mean	2.51E-02	3.60E-02	3.32E-02	3.78E-03	9.19E-03	8.56E-03	1.61E-02	3.14E-02	3.06E-02	2.57E-02	4.79E-02	4.96E-02	7.68E-03	1.59E-02	1.50E-02	4.62E-03	1.32E-02	1.19E-02	5.68E-03	1.35E-02	1.28E-02
t	variance	1.05E-04	9.09E-06	1.16E-05	4.58E-07	6.26E-07	6.16E-07	3.70E-05	7.54E-06	7.92E-06	2.28E-04	1.84E-05	1.81E-05	3.98E-06	1.84E-06	2.13E-06	1.10E-06	1.35E-06	1.47E-06	1.78E-06	1.33E-06	1.39E-06
K (mg/l)	mean	3.22E-03	8.55E-03	8.15E-03	5.62E-04	2.10E-03	1.99E-03	2.64E-03	7.49E-03	7.34E-03	4.33E-03	1.19E-02	1.19E-02	1.21E-03	3.78E-03	3.71E-03	7.76E-04	3.07E-03	2.93E-03	9.43E-04	3.21E-03	3.10E-03
t	variance	2.03E-06	4.94E-07	5.65E-07	9.11E-09	3.04E-08	3.82E-08	8.52E-07	3.77E-07	5.04E-07	7.60E-06	1.05E-06	1.18E-06	8.11E-08	9.89E-08	1.36E-07	3.45E-08	6.67E-08	8.80E-08	3.82E-08	7.00E-08	7.17E-08
C/N	mean	1.40E-02	1.40E-02	1.26E-02	2.31E-03	3.48E-03	3.20E-03	1.15E-02	1.20E-02	1.17E-02	2.13E-02	1.74E-02	1.89E-02	5.76E-03	5.98E-03	5.43E-03	4.34E-03	5.24E-03	4.68E-03	4.47E-03	5.40E-03	4.79E-03
t	variance	3.96E-05	1.40E-06	1.71E-06	2.57E-07	1.06E-07	9.38E-08	1.84E-05	1.20E-06	1.34E-06	1.38E-04	2.61E-06	3.18E-06	2.64E-06	2.67E-07	4.86E-07	1.12E-06	2.14E-07	3.03E-07	1.22E-06	2.15E-07	2.23E-07
Change in	mean	3.81E+00	1.40E+01	1.73E+01	1.49E+00	4.02E+00	4.21E+00	NA	NA	NA	1.00E+01	1.74E+01	2.51E+01	3.99E+00	7.03E+00	7.92E+00	1.50E+00	5.62E+00	6.18E+00	2.29E+00	5.93E+00	6.57E+00
SOC (%)	variance	3.79E+00	1.40E+00	3.78E+00	1.06E-01	1.31E-01	2.21E-01	NA	NA	NA	4.57E+01	4.51E+00	9.39E+00	1.47E+00	3.42E-01	8.30E-01	2.31E-01	2.33E-01	4.84E-01	4.02E-01	2.45E-01	5.47E-01
Distance (km)		4.58E+03	5.47E+03	4.07E+03																		

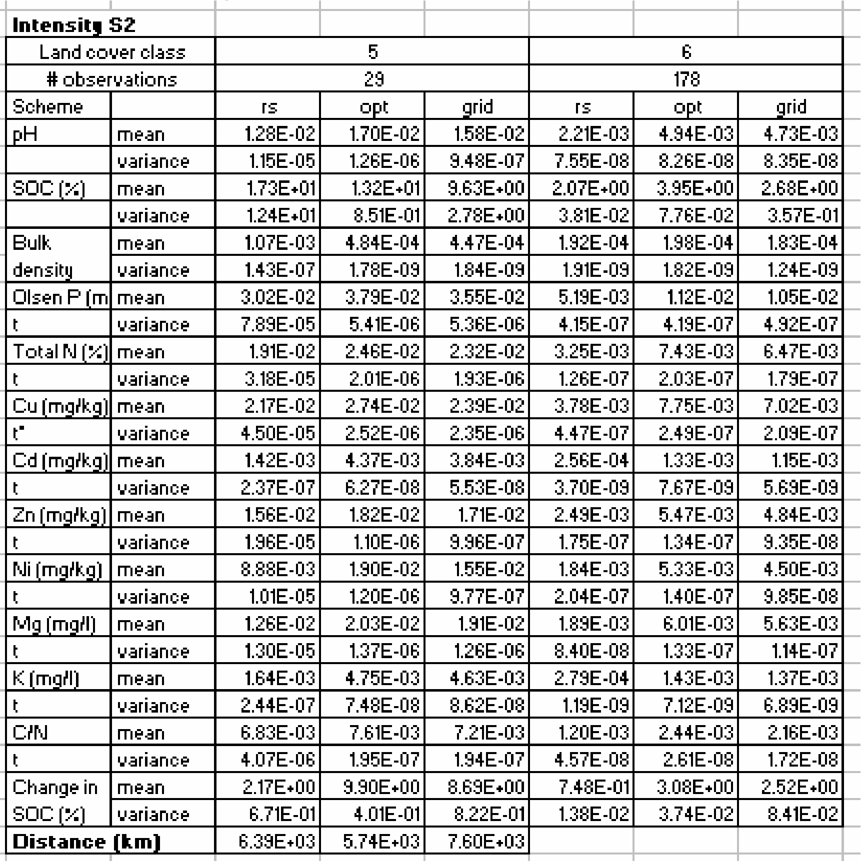
Intensity S1 cont



Intensity S1 cont

Land cover class		14			15		
# observations		29			10		
Scheme		rs	opt	grid	rs	opt	grid
pH	mean	1.34E-02	1.63E-02	1.52E-02	3.94E-02	3.91E-02	4.18E-02
	variance	1.56E-05	1.88E-06	4.28E-06	3.83E-04	1.30E-05	1.38E-05
SOC (%)	mean	7.15E+00	1.24E+01	1.01E+01	3.89E+01	2.81E+01	2.68E+01
	variance	1.06E+01	1.09E+00	2.07E+00	3.87E+02	9.45E+00	1.23E+01
Bulk density (g/cm3)	mean	1.27E-03	5.37E-04	4.94E-04	3.63E-03	1.12E-03	8.48E-04
	variance	2.30E-07	2.91E-09	4.98E-09	5.21E-06	1.40E-08	6.90E-09
Olsen P (mg/l)	mean	3.15E-02	3.85E-02	3.53E-02	9.17E-02	9.32E-02	9.66E-02
t	variance	7.87E-05	1.09E-05	2.09E-05	3.72E-03	6.52E-05	6.86E-05
Total N (%)	mean	1.10E-02	2.58E-02	2.24E-02	2.79E-02	6.17E-02	5.81E-02
t	variance	1.78E-05	4.76E-06	5.69E-06	4.20E-04	2.70E-05	3.48E-05
Cu (mg/kg)	mean	2.37E-02	2.81E-02	2.38E-02	6.97E-02	6.43E-02	6.18E-02
t"	variance	4.20E-05	5.89E-06	7.40E-06	2.70E-03	2.91E-05	3.95E-05
Cd (mg/kg)	mean	1.60E-03	4.56E-03	3.99E-03	5.94E-03	1.02E-02	9.84E-03
t	variance	3.78E-07	1.51E-07	1.53E-07	1.37E-05	7.49E-07	1.12E-06
Zn (mg/kg)	mean	1.56E-02	1.98E-02	1.62E-02	4.28E-02	4.25E-02	4.18E-02
t	variance	3.08E-05	2.81E-06	3.09E-06	5.18E-04	1.32E-05	1.73E-05
Ni (mg/kg)	mean	1.53E-02	1.92E-02	1.57E-02	4.56E-02	4.10E-02	4.08E-02
t	variance	2.96E-05	2.61E-06	4.19E-06	7.52E-04	1.21E-05	1.97E-05
Mg (mg/l)	mean	7.94E-03	2.14E-02	1.97E-02	1.86E-02	4.90E-02	4.88E-02
t	variance	7.17E-06	3.42E-06	3.59E-06	9.91E-05	1.73E-05	2.00E-05
K (mg/l)	mean	1.41E-03	4.89E-03	4.60E-03	3.40E-03	1.19E-02	1.18E-02
t	variance	1.47E-07	1.72E-07	2.13E-07	4.71E-06	9.83E-07	1.01E-06
C/N	mean	6.81E-03	8.34E-03	7.23E-03	2.03E-02	1.93E-02	1.85E-02
t	variance	5.21E-06	5.17E-07	6.02E-07	1.45E-04	2.77E-06	3.22E-06
Change in SOC (%)	mean	1.17E+00	9.04E+00	9.68E+00	8.71E+00	1.83E+01	2.48E+01
	variance	4.73E-01	6.43E-01	1.21E+00	3.20E+01	3.85E+00	8.01E+00

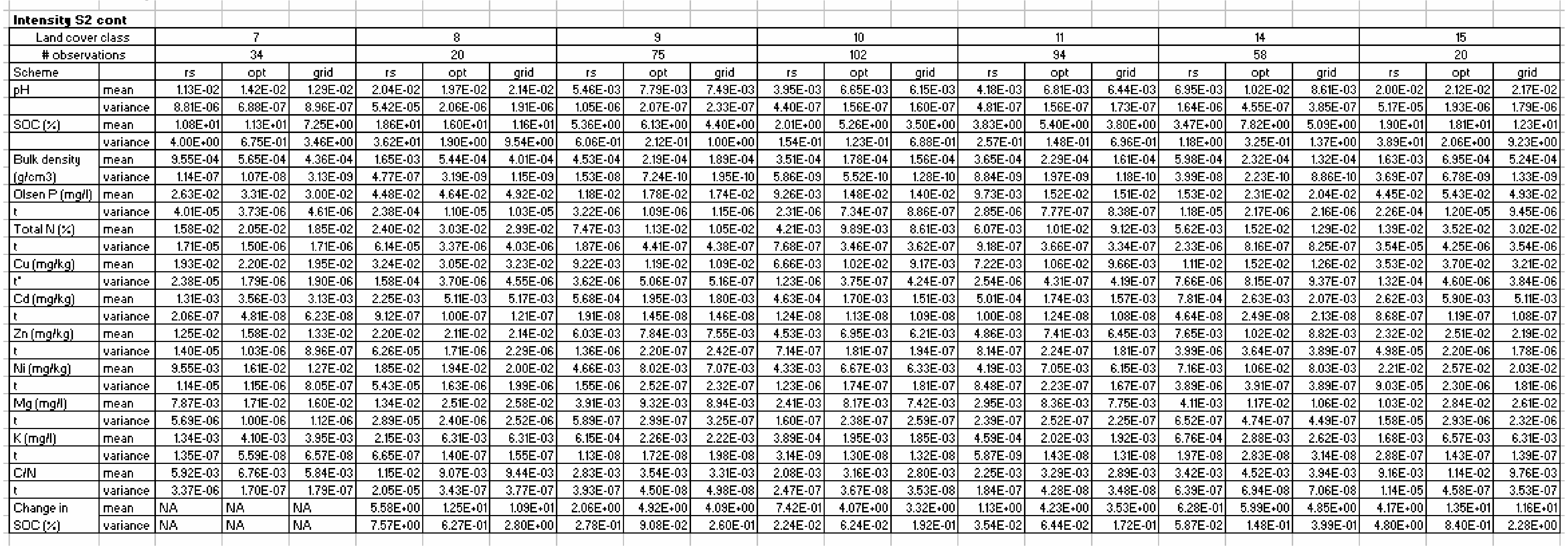
Intensity S2



Intensity S2

Land cover class		5			6		
# observations		29			178		
Scheme		rs	opt	grid	rs	opt	grid
pH	mean	1.28E-02	1.70E-02	1.58E-02	2.21E-03	4.94E-03	4.73E-03
	variance	1.15E-05	1.26E-06	9.48E-07	7.55E-08	8.26E-08	8.35E-08
SOC (%)	mean	1.73E+01	1.32E+01	9.63E+00	2.07E+00	3.95E+00	2.68E+00
	variance	1.24E+01	8.51E-01	2.78E+00	3.81E-02	7.76E-02	3.57E-01
Bulk density	mean	1.07E-03	4.84E-04	4.47E-04	1.92E-04	1.98E-04	1.83E-04
	variance	1.43E-07	1.78E-09	1.84E-09	1.91E-09	1.82E-09	1.24E-09
Olsen P (m	mean	3.02E-02	3.79E-02	3.55E-02	5.19E-03	1.12E-02	1.05E-02
t	variance	7.89E-05	5.41E-06	5.36E-06	4.15E-07	4.19E-07	4.92E-07
Total N (%)	mean	1.91E-02	2.46E-02	2.32E-02	3.25E-03	7.43E-03	6.47E-03
t	variance	3.18E-05	2.01E-06	1.93E-06	1.26E-07	2.03E-07	1.79E-07
Cu (mg/kg)	mean	2.17E-02	2.74E-02	2.39E-02	3.78E-03	7.75E-03	7.02E-03
t"	variance	4.50E-05	2.52E-06	2.35E-06	4.47E-07	2.49E-07	2.09E-07
Cd (mg/kg)	mean	1.42E-03	4.37E-03	3.84E-03	2.56E-04	1.33E-03	1.15E-03
t	variance	2.37E-07	6.27E-08	5.53E-08	3.70E-09	7.67E-09	5.69E-09
Zn (mg/kg)	mean	1.56E-02	1.82E-02	1.71E-02	2.49E-03	5.47E-03	4.84E-03
t	variance	1.96E-05	1.10E-06	9.96E-07	1.75E-07	1.34E-07	9.35E-08
Ni (mg/kg)	mean	8.88E-03	1.90E-02	1.55E-02	1.84E-03	5.33E-03	4.50E-03
t	variance	1.01E-05	1.20E-06	9.77E-07	2.04E-07	1.40E-07	9.85E-08
Mg (mg/l)	mean	1.26E-02	2.03E-02	1.91E-02	1.89E-03	6.01E-03	5.63E-03
t	variance	1.30E-05	1.37E-06	1.26E-06	8.40E-08	1.33E-07	1.14E-07
K (mg/l)	mean	1.64E-03	4.75E-03	4.63E-03	2.79E-04	1.43E-03	1.37E-03
t	variance	2.44E-07	7.48E-08	8.62E-08	1.19E-09	7.12E-09	6.89E-09
C/N	mean	6.83E-03	7.61E-03	7.21E-03	1.20E-03	2.44E-03	2.16E-03
t	variance	4.07E-06	1.95E-07	1.94E-07	4.57E-08	2.61E-08	1.72E-08
Change in SOC (%)	mean	2.17E+00	9.90E+00	8.69E+00	7.48E-01	3.08E+00	2.52E+00
	variance	6.71E-01	4.01E-01	8.22E-01	1.38E-02	3.74E-02	8.41E-02
Distance (km)		6.39E+03	5.74E+03	7.60E+03			

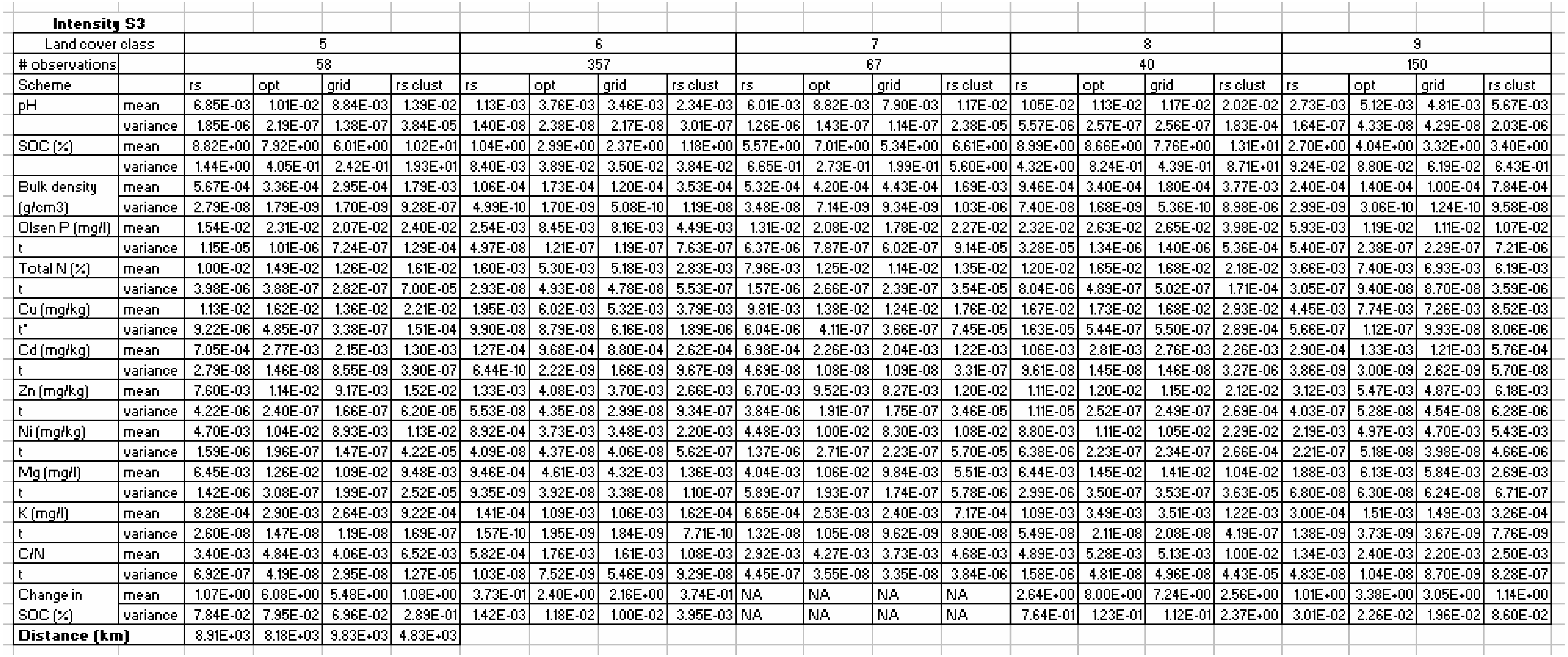
Intensity S2 cont



Intensity S2 cont

Land cover class		7			8			9			10			11			14			15		
# observations		34			20			75			102			94			58			20		
Scheme		rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid
pH	mean	1.13E-02	1.42E-02	1.29E-02	2.04E-02	1.97E-02	2.14E-02	5.46E-03	7.79E-03	7.49E-03	3.95E-03	6.65E-03	6.15E-03	4.18E-03	6.81E-03	6.44E-03	6.95E-03	1.02E-02	8.61E-03	2.00E-02	2.12E-02	2.17E-02
	variance	8.81E-06	6.88E-07	8.96E-07	5.42E-05	2.06E-06	1.91E-06	1.05E-06	2.07E-07	2.33E-07	4.40E-07	1.56E-07	1.60E-07	4.81E-07	1.56E-07	1.73E-07	1.64E-06	4.55E-07	3.85E-07	5.17E-05	1.93E-06	1.79E-06
SOC (%)	mean	1.08E+01	1.13E+01	7.25E+00	1.86E+01	1.60E+01	1.16E+01	5.36E+00	6.13E+00	4.40E+00	2.01E+00	5.26E+00	3.50E+00	3.83E+00	5.40E+00	3.80E+00	3.47E+00	7.82E+00	5.09E+00	1.90E+01	1.81E+01	1.23E+01
	variance	4.00E+00	6.75E-01	3.46E+00	3.62E+01	1.90E+00	9.54E+00	6.06E-01	2.12E-01	1.00E+00	1.54E-01	1.23E-01	6.88E-01	2.57E-01	1.48E-01	6.96E-01	1.18E+00	3.25E-01	1.37E+00	3.89E+01	2.06E+00	9.23E+00
Bulk density	mean	9.55E-04	5.65E-04	4.36E-04	1.65E-03	5.44E-04	4.01E-04	4.53E-04	2.19E-04	1.89E-04	3.51E-04	1.78E-04	1.56E-04	3.65E-04	2.29E-04	1.61E-04	5.98E-04	2.32E-04	1.32E-04	1.63E-03	6.95E-04	5.24E-04
(g/cm3)	variance	1.14E-07	1.07E-08	3.13E-09	4.77E-07	3.19E-09	1.15E-09	1.53E-08	7.24E-10	1.95E-10	5.86E-09	5.52E-10	1.28E-10	8.84E-09	1.97E-09	1.18E-10	3.99E-08	2.23E-10	8.86E-10	3.69E-07	6.78E-09	1.33E-09
Olsen P (mg/l)	mean	2.63E-02	3.31E-02	3.00E-02	4.48E-02	4.64E-02	4.92E-02	1.18E-02	1.78E-02	1.74E-02	9.26E-03	1.48E-02	1.40E-02	9.73E-03	1.52E-02	1.51E-02	1.53E-02	2.31E-02	2.04E-02	4.45E-02	5.43E-02	4.93E-02
t	variance	4.01E-05	3.73E-06	4.61E-06	2.38E-04	1.10E-05	1.03E-05	3.22E-06	1.09E-06	1.15E-06	2.31E-06	7.34E-07	8.86E-07	2.85E-06	7.77E-07	8.38E-07	1.18E-05	2.17E-06	2.16E-06	2.26E-04	1.20E-05	9.45E-06
Total N (%)	mean	1.58E-02	2.05E-02	1.85E-02	2.40E-02	3.03E-02	2.99E-02	7.47E-03	1.13E-02	1.05E-02	4.21E-03	9.89E-03	8.61E-03	6.07E-03	1.01E-02	9.12E-03	5.62E-03	1.52E-02	1.29E-02	1.39E-02	3.52E-02	3.02E-02
t	variance	1.71E-05	1.50E-06	1.71E-06	6.14E-05	3.37E-06	4.03E-06	1.87E-06	4.41E-07	4.38E-07	7.68E-07	3.46E-07	3.62E-07	9.18E-07	3.66E-07	3.34E-07	2.33E-06	8.16E-07	8.25E-07	3.54E-05	4.25E-06	3.54E-06
Cu (mg/kg)	mean	1.93E-02	2.20E-02	1.95E-02	3.24E-02	3.05E-02	3.23E-02	9.22E-03	1.19E-02	1.09E-02	6.66E-03	1.02E-02	9.17E-03	7.22E-03	1.06E-02	9.66E-03	1.11E-02	1.52E-02	1.26E-02	3.53E-02	3.70E-02	3.21E-02
t*	variance	2.38E-05	1.79E-06	1.90E-06	1.58E-04	3.70E-06	4.55E-06	3.62E-06	5.06E-07	5.16E-07	1.23E-06	3.75E-07	4.24E-07	2.54E-06	4.31E-07	4.19E-07	7.66E-06	8.15E-07	9.37E-07	1.32E-04	4.60E-06	3.84E-06
Cd (mg/kg)	mean	1.31E-03	3.56E-03	3.13E-03	2.25E-03	5.11E-03	5.17E-03	5.68E-04	1.95E-03	1.80E-03	4.63E-04	1.70E-03	1.51E-03	5.01E-04	1.74E-03	1.57E-03	7.81E-04	2.63E-03	2.07E-03	2.62E-03	5.90E-03	5.11E-03
t	variance	2.06E-07	4.81E-08	6.23E-08	9.12E-07	1.00E-07	1.21E-07	1.91E-08	1.45E-08	1.46E-08	1.24E-08	1.13E-08	1.09E-08	1.00E-08	1.24E-08	1.08E-08	4.64E-08	2.49E-08	2.13E-08	8.68E-07	1.19E-07	1.08E-07
Zn (mg/kg)	mean	1.25E-02	1.58E-02	1.33E-02	2.20E-02	2.11E-02	2.14E-02	6.03E-03	7.84E-03	7.55E-03	4.53E-03	6.95E-03	6.21E-03	4.86E-03	7.41E-03	6.45E-03	7.65E-03	1.02E-02	8.82E-03	2.32E-02	2.51E-02	2.19E-02
t	variance	1.40E-05	1.03E-06	8.96E-07	6.26E-05	1.71E-06	2.29E-06	1.36E-06	2.20E-07	2.42E-07	7.14E-07	1.81E-07	1.94E-07	8.14E-07	2.24E-07	1.81E-07	3.99E-06	3.64E-07	3.89E-07	4.98E-05	2.20E-06	1.78E-06
Ni (mg/kg)	mean	9.55E-03	1.61E-02	1.27E-02	1.85E-02	1.94E-02	2.00E-02	4.66E-03	8.02E-03	7.07E-03	4.33E-03	6.67E-03	6.33E-03	4.19E-03	7.05E-03	6.15E-03	7.16E-03	1.06E-02	8.03E-03	2.21E-02	2.57E-02	2.03E-02
t	variance	1.14E-05	1.15E-06	8.05E-07	5.43E-05	1.63E-06	1.99E-06	1.55E-06	2.52E-07	2.32E-07	1.23E-06	1.74E-07	1.81E-07	8.48E-07	2.23E-07	1.67E-07	3.89E-06	3.91E-07	3.89E-07	9.03E-05	2.30E-06	1.81E-06
Mg (mg/l)	mean	7.87E-03	1.71E-02	1.60E-02	1.34E-02	2.51E-02	2.58E-02	3.91E-03	9.32E-03	8.94E-03	2.41E-03	8.17E-03	7.42E-03	2.95E-03	8.36E-03	7.75E-03	4.11E-03	1.17E-02	1.06E-02	1.03E-02	2.84E-02	2.61E-02
t	variance	5.69E-06	1.00E-06	1.12E-06	2.89E-05	2.40E-06	2.52E-06	5.89E-07	2.99E-07	3.25E-07	1.60E-07	2.38E-07	2.59E-07	2.39E-07	2.52E-07	2.25E-07	6.52E-07	4.74E-07	4.49E-07	1.58E-05	2.93E-06	2.32E-06
K (mg/l)	mean	1.34E-03	4.10E-03	3.95E-03	2.15E-03	6.31E-03	6.31E-03	6.15E-04	2.26E-03	2.22E-03	3.89E-04	1.95E-03	1.85E-03	4.59E-04	2.02E-03	1.92E-03	6.76E-04	2.88E-03	2.62E-03	1.68E-03	6.57E-03	6.31E-03
t	variance	1.35E-07	5.59E-08	6.57E-08	6.65E-07	1.40E-07	1.55E-07	1.13E-08	1.72E-08	1.98E-08	3.14E-09	1.30E-08	1.32E-08	5.87E-09	1.43E-08	1.31E-08	1.97E-08	2.83E-08	3.14E-08	2.88E-07	1.43E-07	1.39E-07
C/N	mean	5.92E-03	6.76E-03	5.84E-03	1.15E-02	9.07E-03	9.44E-03	2.83E-03	3.54E-03	3.31E-03	2.08E-03	3.16E-03	2.80E-03	2.25E-03	3.29E-03	2.89E-03	3.42E-03	4.52E-03	3.94E-03	9.16E-03	1.14E-02	9.76E-03
t	variance	3.37E-06	1.70E-07	1.79E-07	2.05E-05	3.43E-07	3.77E-07	3.93E-07	4.50E-08	4.98E-08	2.47E-07	3.67E-08	3.53E-08	1.84E-07	4.28E-08	3.48E-08	6.39E-07	6.94E-08	7.06E-08	1.14E-05	4.58E-07	3.53E-07
Change in	mean	NA	NA	NA	5.58E+00	1.25E+01	1.09E+01	2.06E+00	4.92E+00	4.09E+00	7.42E-01	4.07E+00	3.32E+00	1.13E+00	4.23E+00	3.53E+00	6.28E-01	5.99E+00	4.85E+00	4.17E+00	1.35E+01	1.16E+01
SOC (%)	variance	NA	NA	NA	7.57E+00	6.27E-01	2.80E+00	2.78E-01	9.08E-02	2.60E-01	2.24E-02	6.24E-02	1.92E-01	3.54E-02	6.44E-02	1.72E-01	5.87E-02	1.48E-01	3.99E-01	4.80E+00	8.40E-01	2.28E+00

Intensity S3



Intensity S3

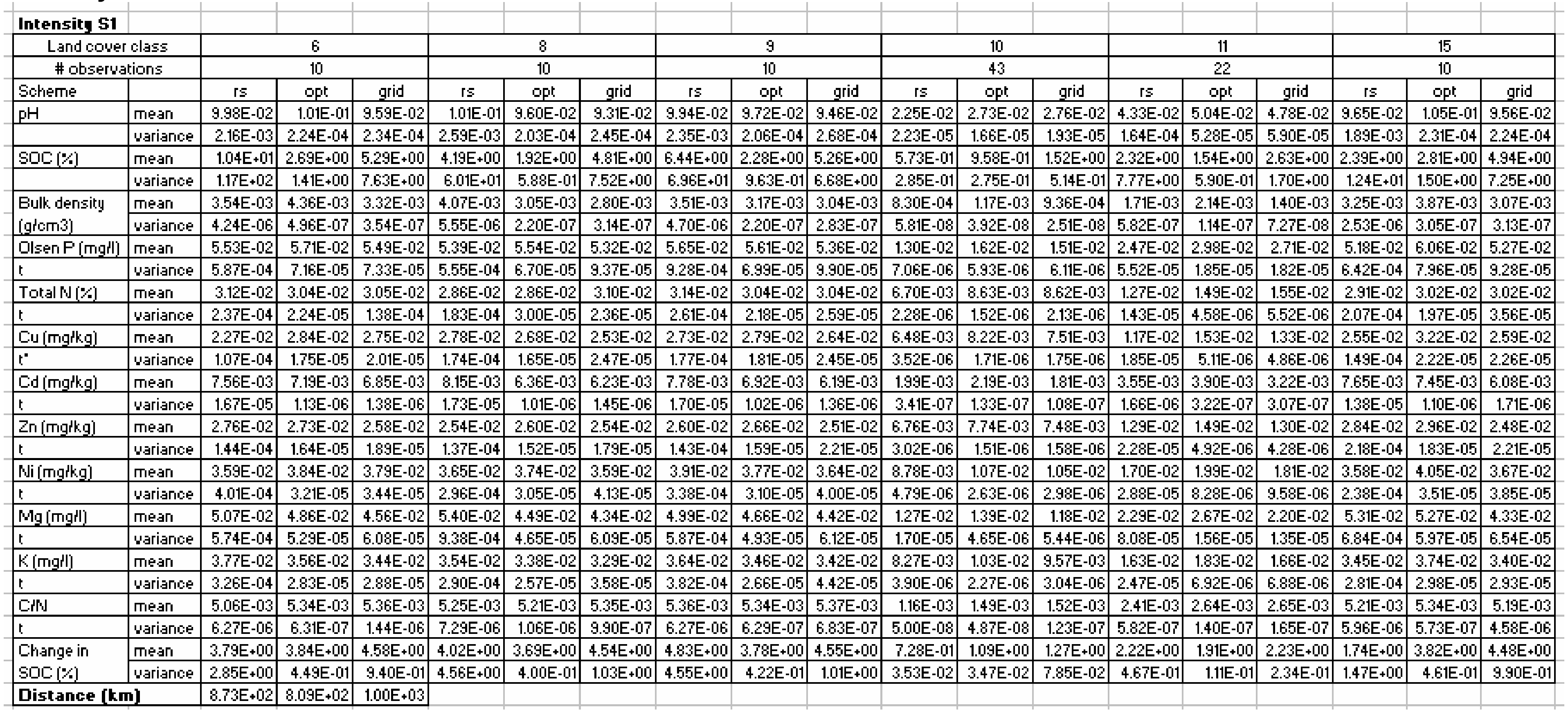
Land cover class		5				6				7				8				9			
# observations		58				357				67				40				150			
Scheme		rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust
pH	mean	6.85E-03	1.01E-02	8.84E-03	1.39E-02	1.13E-03	3.76E-03	3.46E-03	2.34E-03	6.01E-03	8.82E-03	7.90E-03	1.17E-02	1.05E-02	1.13E-02	1.17E-02	2.02E-02	2.73E-03	5.12E-03	4.81E-03	5.67E-03
	variance	1.85E-06	2.19E-07	1.38E-07	3.84E-05	1.40E-08	2.38E-08	2.17E-08	3.01E-07	1.26E-06	1.43E-07	1.14E-07	2.38E-05	5.57E-06	2.57E-07	2.56E-07	1.83E-04	1.64E-07	4.33E-08	4.29E-08	2.03E-06
SOC (%)	mean	8.82E+00	7.92E+00	6.01E+00	1.02E+01	1.04E+00	2.99E+00	2.37E+00	1.18E+00	5.57E+00	7.01E+00	5.34E+00	6.61E+00	8.99E+00	8.66E+00	7.76E+00	1.31E+01	2.70E+00	4.04E+00	3.32E+00	3.40E+00
	variance	1.44E+00	4.05E-01	2.42E-01	1.93E+01	8.40E-03	3.89E-02	3.50E-02	3.84E-02	6.65E-01	2.73E-01	1.99E-01	5.60E+00	4.32E+00	8.24E-01	4.39E-01	8.71E+01	9.24E-02	8.80E-02	6.19E-02	6.43E-01
Bulk density (g/cm3)	mean	5.67E-04	3.36E-04	2.95E-04	1.79E-03	1.06E-04	1.73E-04	1.20E-04	3.53E-04	5.32E-04	4.20E-04	4.43E-04	1.69E-03	9.46E-04	3.40E-04	1.80E-04	3.77E-03	2.40E-04	1.40E-04	1.00E-04	7.84E-04
	variance	2.79E-08	1.79E-09	1.70E-09	9.28E-07	4.99E-10	1.70E-09	5.08E-10	1.19E-08	3.48E-08	7.14E-09	9.34E-09	1.03E-06	7.40E-08	1.68E-09	5.36E-10	8.98E-06	2.99E-09	3.06E-10	1.24E-10	9.58E-08
Olsen P (mg/l)	mean	1.54E-02	2.31E-02	2.07E-02	2.40E-02	2.54E-03	8.45E-03	8.16E-03	4.49E-03	1.31E-02	2.08E-02	1.78E-02	2.27E-02	2.32E-02	2.63E-02	2.65E-02	3.98E-02	5.93E-03	1.19E-02	1.11E-02	1.07E-02
t	variance	1.15E-05	1.01E-06	7.24E-07	1.29E-04	4.97E-08	1.21E-07	1.19E-07	7.63E-07	6.37E-06	7.87E-07	6.02E-07	9.14E-05	3.28E-05	1.34E-06	1.40E-06	5.36E-04	5.40E-07	2.38E-07	2.29E-07	7.21E-06
Total N (%)	mean	1.00E-02	1.49E-02	1.26E-02	1.61E-02	1.60E-03	5.30E-03	5.18E-03	2.83E-03	7.96E-03	1.25E-02	1.14E-02	1.35E-02	1.20E-02	1.65E-02	1.68E-02	2.18E-02	3.66E-03	7.40E-03	6.93E-03	6.19E-03
t	variance	3.98E-06	3.88E-07	2.82E-07	7.00E-05	2.93E-08	4.93E-08	4.78E-08	5.53E-07	1.57E-06	2.66E-07	2.39E-07	3.54E-05	8.04E-06	4.89E-07	5.02E-07	1.71E-04	3.05E-07	9.40E-08	8.70E-08	3.59E-06
Cu (mg/kg)	mean	1.13E-02	1.62E-02	1.36E-02	2.21E-02	1.95E-03	6.02E-03	5.32E-03	3.79E-03	9.81E-03	1.38E-02	1.24E-02	1.76E-02	1.67E-02	1.73E-02	1.68E-02	2.93E-02	4.45E-03	7.74E-03	7.26E-03	8.52E-03
t'	variance	9.22E-06	4.85E-07	3.38E-07	1.51E-04	9.90E-08	8.79E-08	6.16E-08	1.89E-06	6.04E-06	4.11E-07	3.66E-07	7.45E-05	1.63E-05	5.44E-07	5.50E-07	2.89E-04	5.66E-07	1.12E-07	9.93E-08	8.06E-06
Cd (mg/kg)	mean	7.05E-04	2.77E-03	2.15E-03	1.30E-03	1.27E-04	9.68E-04	8.80E-04	2.62E-04	6.98E-04	2.26E-03	2.04E-03	1.22E-03	1.06E-03	2.81E-03	2.76E-03	2.26E-03	2.90E-04	1.33E-03	1.21E-03	5.76E-04
t	variance	2.79E-08	1.46E-08	8.55E-09	3.90E-07	6.44E-10	2.22E-09	1.66E-09	9.67E-09	4.69E-08	1.08E-08	1.09E-08	3.31E-07	9.61E-08	1.45E-08	1.46E-08	3.27E-06	3.86E-09	3.00E-09	2.62E-09	5.70E-08
Zn (mg/kg)	mean	7.60E-03	1.14E-02	9.17E-03	1.52E-02	1.33E-03	4.08E-03	3.70E-03	2.66E-03	6.70E-03	9.52E-03	8.27E-03	1.20E-02	1.11E-02	1.20E-02	1.15E-02	2.12E-02	3.12E-03	5.47E-03	4.87E-03	6.18E-03
t	variance	4.22E-06	2.40E-07	1.66E-07	6.20E-05	5.53E-08	4.35E-08	2.99E-08	9.34E-07	3.84E-06	1.91E-07	1.75E-07	3.46E-05	1.11E-05	2.52E-07	2.49E-07	2.69E-04	4.03E-07	5.28E-08	4.54E-08	6.28E-06
Ni (mg/kg)	mean	4.70E-03	1.04E-02	8.93E-03	1.13E-02	8.92E-04	3.73E-03	3.48E-03	2.20E-03	4.48E-03	1.00E-02	8.30E-03	1.08E-02	8.80E-03	1.11E-02	1.05E-02	2.29E-02	2.19E-03	4.97E-03	4.70E-03	5.43E-03
t	variance	1.59E-06	1.96E-07	1.47E-07	4.22E-05	4.09E-08	4.37E-08	4.06E-08	5.62E-07	1.37E-06	2.71E-07	2.23E-07	5.70E-05	6.38E-06	2.23E-07	2.34E-07	2.66E-04	2.21E-07	5.18E-08	3.98E-08	4.66E-06
Mg (mg/l)	mean	6.45E-03	1.26E-02	1.09E-02	9.48E-03	9.46E-04	4.61E-03	4.32E-03	1.36E-03	4.04E-03	1.06E-02	9.84E-03	5.51E-03	6.44E-03	1.45E-02	1.41E-02	1.04E-02	1.88E-03	6.13E-03	5.84E-03	2.69E-03
t	variance	1.42E-06	3.08E-07	1.99E-07	2.52E-05	9.35E-09	3.92E-08	3.38E-08	1.10E-07	5.89E-07	1.93E-07	1.74E-07	5.78E-06	2.99E-06	3.50E-07	3.53E-07	3.63E-05	6.80E-08	6.30E-08	6.24E-08	6.71E-07
K (mg/l)	mean	8.28E-04	2.90E-03	2.64E-03	9.22E-04	1.41E-04	1.09E-03	1.06E-03	1.62E-04	6.65E-04	2.53E-03	2.40E-03	7.17E-04	1.09E-03	3.49E-03	3.51E-03	1.22E-03	3.00E-04	1.51E-03	1.49E-03	3.26E-04
t	variance	2.60E-08	1.47E-08	1.19E-08	1.69E-07	1.57E-10	1.95E-09	1.84E-09	7.71E-10	1.32E-08	1.05E-08	9.62E-09	8.90E-08	5.49E-08	2.11E-08	2.08E-08	4.19E-07	1.38E-09	3.73E-09	3.67E-09	7.76E-09
C/N	mean	3.40E-03	4.84E-03	4.06E-03	6.52E-03	5.82E-04	1.76E-03	1.61E-03	1.08E-03	2.92E-03	4.27E-03	3.73E-03	4.68E-03	4.89E-03	5.28E-03	5.13E-03	1.00E-02	1.34E-03	2.40E-03	2.20E-03	2.50E-03
t	variance	6.92E-07	4.19E-08	2.95E-08	1.27E-05	1.03E-08	7.52E-09	5.46E-09	9.29E-08	4.45E-07	3.55E-08	3.35E-08	3.84E-06	1.58E-06	4.81E-08	4.96E-08	4.43E-05	4.83E-08	1.04E-08	8.70E-09	8.28E-07
Change in SOC (%)	mean	1.07E+00	6.08E+00	5.48E+00	1.08E+00	3.73E-01	2.40E+00	2.16E+00	3.74E-01	NA	NA	NA	NA	2.64E+00	8.00E+00	7.24E+00	2.56E+00	1.01E+00	3.38E+00	3.05E+00	1.14E+00
	variance	7.84E-02	7.95E-02	6.96E-02	2.89E-01	1.42E-03	1.18E-02	1.00E-02	3.95E-03	NA	NA	NA	NA	7.64E-01	1.23E-01	1.12E-01	2.37E+00	3.01E-02	2.26E-02	1.96E-02	8.60E-02
Distance (km)		8.91E+03	8.18E+03	9.83E+03	4.83E+03																

Intensity S3 cont.

Intensity S3 cont.																	
Land cover class		10				11				14				15			
# observations		204				187				117				40			
Scheme		rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust
pH	mean	1.97E-03	4.56E-03	4.32E-03	4.05E-03	2.17E-03	4.65E-03	4.32E-03	4.25E-03	3.38E-03	6.32E-03	5.28E-03	7.03E-03	9.58E-03	1.32E-02	1.15E-02	2.02E-02
	variance	6.64E-08	3.44E-08	3.32E-08	1.09E-06	6.55E-08	3.57E-08	3.45E-08	1.09E-06	3.12E-07	7.31E-08	5.94E-08	5.81E-06	5.29E-06	3.07E-07	2.63E-07	1.13E-04
SOC (%)	mean	1.01E+00	3.59E+00	2.86E+00	1.33E+00	1.95E+00	3.69E+00	2.95E+00	2.39E+00	1.79E+00	4.88E+00	3.68E+00	2.73E+00	9.30E+00	1.02E+01	7.63E+00	1.38E+01
	variance	3.43E-02	6.50E-02	4.98E-02	1.20E-01	6.91E-02	7.55E-02	5.54E-02	3.40E-01	2.01E-01	1.05E-01	8.97E-02	1.34E+00	4.04E+00	5.82E-01	4.15E-01	6.19E+01
Bulk density (g/cm3)	mean	1.78E-04	1.10E-04	2.09E-05	6.17E-04	1.98E-04	1.91E-04	7.48E-05	6.33E-04	3.00E-04	1.24E-04	1.22E-04	9.79E-04	8.38E-04	4.60E-04	1.32E-04	2.61E-03
	variance	1.66E-09	8.09E-11	7.71E-10	4.58E-08	2.09E-09	1.70E-09	2.14E-10	4.28E-08	7.37E-09	4.39E-11	4.99E-11	2.11E-07	7.95E-08	5.06E-09	9.04E-10	3.26E-06
Olsen P (mg/l)	mean	4.44E-03	1.06E-02	9.86E-03	7.90E-03	4.78E-03	1.05E-02	1.03E-02	8.16E-03	7.58E-03	1.41E-02	1.25E-02	1.31E-02	2.25E-02	3.11E-02	2.63E-02	4.48E-02
t	variance	2.83E-07	1.88E-07	1.72E-07	3.29E-06	3.21E-07	1.86E-07	1.86E-07	3.87E-06	1.36E-06	3.33E-07	3.02E-07	1.59E-05	3.74E-05	1.73E-06	1.31E-06	9.57E-04
Total N (%)	mean	2.14E-03	6.47E-03	5.94E-03	3.62E-03	3.01E-03	7.24E-03	6.30E-03	5.14E-03	2.87E-03	9.49E-03	7.92E-03	4.73E-03	7.09E-03	1.88E-02	1.64E-02	1.07E-02
t	variance	1.01E-07	7.04E-08	6.83E-08	1.48E-06	1.54E-07	9.21E-08	7.56E-08	2.13E-06	5.36E-07	1.50E-07	1.14E-07	3.64E-06	6.60E-06	5.89E-07	4.91E-07	6.33E-05
Cu (mg/kg)	mean	3.43E-03	6.88E-03	5.95E-03	6.47E-03	3.72E-03	7.12E-03	6.26E-03	7.22E-03	5.82E-03	9.63E-03	8.15E-03	1.04E-02	1.56E-02	2.22E-02	1.65E-02	3.39E-02
t*	variance	3.04E-07	8.74E-08	9.59E-08	4.05E-06	3.41E-07	1.18E-07	8.91E-08	4.95E-06	1.96E-06	1.57E-07	1.17E-07	2.26E-05	1.68E-05	9.46E-07	5.43E-07	5.60E-04
Cd (mg/kg)	mean	2.32E-04	1.13E-03	9.58E-04	4.77E-04	2.59E-04	1.17E-03	1.04E-03	5.31E-04	4.02E-04	1.54E-03	1.35E-03	8.00E-04	1.35E-03	3.28E-03	2.64E-03	2.59E-03
t	variance	1.88E-09	2.45E-09	2.94E-09	3.58E-08	2.11E-09	3.25E-09	2.41E-09	3.98E-08	1.23E-08	4.22E-09	3.47E-09	1.34E-07	1.11E-07	1.93E-08	1.43E-08	3.54E-06
Zn (mg/kg)	mean	2.32E-03	4.65E-03	4.08E-03	4.47E-03	2.51E-03	5.13E-03	4.24E-03	5.05E-03	3.81E-03	6.20E-03	5.46E-03	7.61E-03	1.08E-02	1.40E-02	1.09E-02	2.19E-02
t	variance	1.99E-07	3.73E-08	4.62E-08	2.07E-06	2.21E-07	6.09E-08	4.38E-08	3.64E-06	7.13E-07	6.52E-08	5.87E-08	9.80E-06	1.06E-05	3.63E-07	2.64E-07	1.57E-04
Ni (mg/kg)	mean	2.07E-03	4.91E-03	3.68E-03	5.11E-03	2.02E-03	4.87E-03	3.95E-03	5.07E-03	3.55E-03	6.55E-03	5.33E-03	8.49E-03	1.01E-02	1.37E-02	1.04E-02	2.27E-02
t	variance	1.94E-07	5.92E-08	5.32E-08	2.94E-06	1.96E-07	8.04E-08	4.42E-08	3.28E-06	8.18E-07	7.79E-08	5.42E-08	1.51E-05	8.32E-06	4.07E-07	2.38E-07	2.26E-04
Mg (mg/l)	mean	1.23E-03	5.70E-03	5.12E-03	1.77E-03	1.53E-03	5.72E-03	5.32E-03	2.22E-03	1.99E-03	7.37E-03	6.70E-03	2.87E-03	5.11E-03	1.65E-02	1.39E-02	6.63E-03
t	variance	2.65E-08	5.52E-08	5.11E-08	2.69E-07	4.93E-08	5.90E-08	5.28E-08	3.41E-07	1.18E-07	9.16E-08	7.97E-08	1.10E-06	2.54E-06	4.99E-07	3.55E-07	1.11E-05
K (mg/l)	mean	1.90E-04	1.38E-03	1.28E-03	2.12E-04	2.37E-04	1.39E-03	1.33E-03	2.72E-04	3.39E-04	1.82E-03	1.68E-03	3.85E-04	8.58E-04	3.82E-03	3.46E-03	1.09E-03
t	variance	5.80E-10	3.19E-09	2.90E-09	2.50E-09	4.24E-10	3.24E-09	3.14E-09	3.62E-09	2.27E-09	5.55E-09	4.81E-09	1.37E-08	4.59E-08	2.55E-08	2.11E-08	4.89E-07
C/N	mean	9.90E-04	2.12E-03	1.83E-03	1.89E-03	1.06E-03	2.15E-03	1.85E-03	1.95E-03	1.72E-03	2.86E-03	2.48E-03	2.95E-03	4.71E-03	6.10E-03	4.73E-03	9.00E-03
t	variance	3.36E-08	8.40E-09	8.79E-09	2.78E-07	3.51E-08	9.15E-09	8.58E-09	3.79E-07	1.57E-07	1.45E-08	1.14E-08	1.26E-06	1.58E-06	6.58E-08	5.26E-08	3.21E-05
Change in SOC (%)	mean	3.77E-01	2.93E+00	2.64E+00	3.89E-01	5.98E-01	3.04E+00	2.74E+00	6.20E-01	3.19E-01	3.87E+00	3.46E+00	3.06E-01	2.19E+00	7.96E+00	7.13E+00	2.20E+00
	variance	2.94E-03	1.80E-02	1.49E-02	1.31E-02	6.15E-03	1.94E-02	1.56E-02	2.09E-02	9.32E-03	3.14E-02	2.75E-02	1.85E-02	6.08E-01	1.28E-01	1.12E-01	1.66E+00

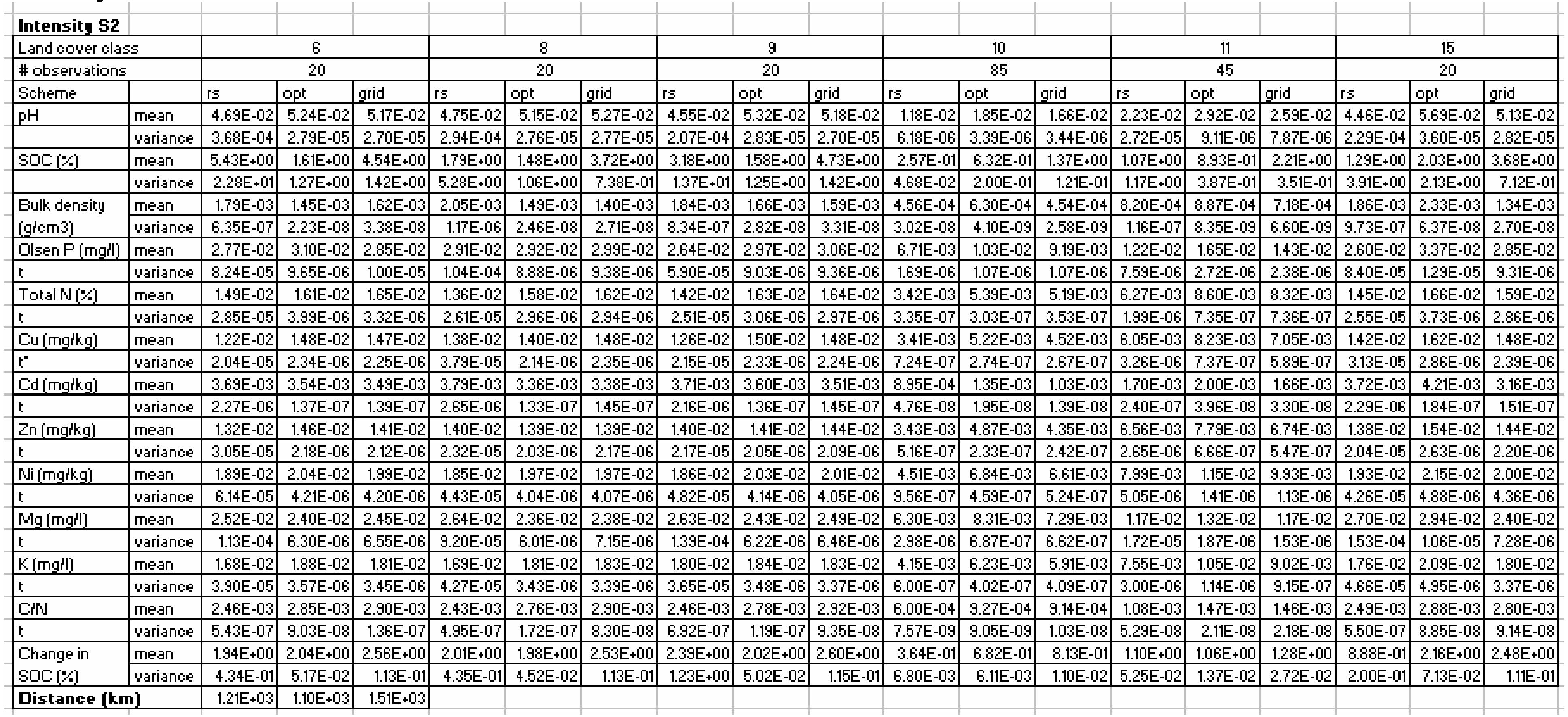
Wales

Intensity S1



Intensity S1																			
Land cover class		6			8			9			10			11			15		
# observations		10			10			10			43			22			10		
Scheme		rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid
pH	mean	9.98E-02	1.01E-01	9.59E-02	1.01E-01	9.60E-02	9.31E-02	9.94E-02	9.72E-02	9.46E-02	2.25E-02	2.73E-02	2.76E-02	4.33E-02	5.04E-02	4.78E-02	9.65E-02	1.05E-01	9.56E-02
	variance	2.16E-03	2.24E-04	2.34E-04	2.59E-03	2.03E-04	2.45E-04	2.35E-03	2.06E-04	2.68E-04	2.23E-05	1.66E-05	1.93E-05	1.64E-04	5.28E-05	5.90E-05	1.89E-03	2.31E-04	2.24E-04
SOC (%)	mean	1.04E+01	2.69E+00	5.29E+00	4.19E+00	1.92E+00	4.81E+00	6.44E+00	2.28E+00	5.26E+00	5.73E-01	9.58E-01	1.52E+00	2.32E+00	1.54E+00	2.63E+00	2.39E+00	2.81E+00	4.94E+00
	variance	1.17E+02	1.41E+00	7.63E+00	6.01E+01	5.88E-01	7.52E+00	6.96E+01	9.63E-01	6.68E+00	2.85E-01	2.75E-01	5.14E-01	7.77E+00	5.90E-01	1.70E+00	1.24E+01	1.50E+00	7.25E+00
Bulk density (g/cm3)	mean	3.54E-03	4.36E-03	3.32E-03	4.07E-03	3.05E-03	2.80E-03	3.51E-03	3.17E-03	3.04E-03	8.30E-04	1.17E-03	9.36E-04	1.71E-03	2.14E-03	1.40E-03	3.25E-03	3.87E-03	3.07E-03
	variance	4.24E-06	4.96E-07	3.54E-07	5.55E-06	2.20E-07	3.14E-07	4.70E-06	2.20E-07	2.83E-07	5.81E-08	3.92E-08	2.51E-08	5.82E-07	1.14E-07	7.27E-08	2.53E-06	3.05E-07	3.13E-07
Olsen P (mg/l)	mean	5.53E-02	5.71E-02	5.49E-02	5.39E-02	5.54E-02	5.32E-02	5.65E-02	5.61E-02	5.36E-02	1.30E-02	1.62E-02	1.51E-02	2.47E-02	2.98E-02	2.71E-02	5.18E-02	6.06E-02	5.27E-02
t	variance	5.87E-04	7.16E-05	7.33E-05	5.55E-04	6.70E-05	9.37E-05	9.28E-04	6.99E-05	9.90E-05	7.06E-06	5.93E-06	6.11E-06	5.52E-05	1.85E-05	1.82E-05	6.42E-04	7.96E-05	9.28E-05
Total N (%)	mean	3.12E-02	3.04E-02	3.05E-02	2.86E-02	2.86E-02	3.10E-02	3.14E-02	3.04E-02	3.04E-02	6.70E-03	8.63E-03	8.62E-03	1.27E-02	1.49E-02	1.55E-02	2.91E-02	3.02E-02	3.02E-02
t	variance	2.37E-04	2.24E-05	1.38E-04	1.83E-04	3.00E-05	2.36E-05	2.61E-04	2.18E-05	2.59E-05	2.28E-06	1.52E-06	2.13E-06	1.43E-05	4.58E-06	5.52E-06	2.07E-04	1.97E-05	3.56E-05
Cu (mg/kg)	mean	2.27E-02	2.84E-02	2.75E-02	2.78E-02	2.68E-02	2.53E-02	2.73E-02	2.79E-02	2.64E-02	6.48E-03	8.22E-03	7.51E-03	1.17E-02	1.53E-02	1.33E-02	2.55E-02	3.22E-02	2.59E-02
t"	variance	1.07E-04	1.75E-05	2.01E-05	1.74E-04	1.65E-05	2.47E-05	1.77E-04	1.81E-05	2.45E-05	3.52E-06	1.71E-06	1.75E-06	1.85E-05	5.11E-06	4.86E-06	1.49E-04	2.22E-05	2.26E-05
Cd (mg/kg)	mean	7.56E-03	7.19E-03	6.85E-03	8.15E-03	6.36E-03	6.23E-03	7.78E-03	6.92E-03	6.19E-03	1.99E-03	2.19E-03	1.81E-03	3.55E-03	3.90E-03	3.22E-03	7.65E-03	7.45E-03	6.08E-03
t	variance	1.67E-05	1.13E-06	1.38E-06	1.73E-05	1.01E-06	1.45E-06	1.70E-05	1.02E-06	1.36E-06	3.41E-07	1.33E-07	1.08E-07	1.66E-06	3.22E-07	3.07E-07	1.38E-05	1.10E-06	1.71E-06
Zn (mg/kg)	mean	2.76E-02	2.73E-02	2.58E-02	2.54E-02	2.60E-02	2.54E-02	2.60E-02	2.66E-02	2.51E-02	6.76E-03	7.74E-03	7.48E-03	1.29E-02	1.49E-02	1.30E-02	2.84E-02	2.96E-02	2.48E-02
t	variance	1.44E-04	1.64E-05	1.89E-05	1.37E-04	1.52E-05	1.79E-05	1.43E-04	1.59E-05	2.21E-05	3.02E-06	1.51E-06	1.58E-06	2.28E-05	4.92E-06	4.28E-06	2.18E-04	1.83E-05	2.21E-05
Ni (mg/kg)	mean	3.59E-02	3.84E-02	3.79E-02	3.65E-02	3.74E-02	3.59E-02	3.91E-02	3.77E-02	3.64E-02	8.78E-03	1.07E-02	1.05E-02	1.70E-02	1.99E-02	1.81E-02	3.58E-02	4.05E-02	3.67E-02
t	variance	4.01E-04	3.21E-05	3.44E-05	2.96E-04	3.05E-05	4.13E-05	3.38E-04	3.10E-05	4.00E-05	4.79E-06	2.63E-06	2.98E-06	2.88E-05	8.28E-06	9.58E-06	2.38E-04	3.51E-05	3.85E-05
Mg (mg/l)	mean	5.07E-02	4.86E-02	4.56E-02	5.40E-02	4.49E-02	4.34E-02	4.99E-02	4.66E-02	4.42E-02	1.27E-02	1.39E-02	1.18E-02	2.29E-02	2.67E-02	2.20E-02	5.31E-02	5.27E-02	4.33E-02
t	variance	5.74E-04	5.29E-05	6.08E-05	9.38E-04	4.65E-05	6.09E-05	5.87E-04	4.93E-05	6.12E-05	1.70E-05	4.65E-06	5.44E-06	8.08E-05	1.56E-05	1.35E-05	6.84E-04	5.97E-05	6.54E-05
K (mg/l)	mean	3.77E-02	3.56E-02	3.44E-02	3.54E-02	3.38E-02	3.29E-02	3.64E-02	3.46E-02	3.42E-02	8.27E-03	1.03E-02	9.57E-03	1.63E-02	1.83E-02	1.66E-02	3.45E-02	3.74E-02	3.40E-02
t	variance	3.26E-04	2.83E-05	2.88E-05	2.90E-04	2.57E-05	3.58E-05	3.82E-04	2.66E-05	4.42E-05	3.90E-06	2.27E-06	3.04E-06	2.47E-05	6.92E-06	6.88E-06	2.81E-04	2.98E-05	2.93E-05
C/N	mean	5.06E-03	5.34E-03	5.36E-03	5.25E-03	5.21E-03	5.35E-03	5.36E-03	5.34E-03	5.37E-03	1.16E-03	1.49E-03	1.52E-03	2.41E-03	2.64E-03	2.65E-03	5.21E-03	5.34E-03	5.19E-03
t	variance	6.27E-06	6.31E-07	1.44E-06	7.29E-06	1.06E-06	9.90E-07	6.27E-06	6.29E-07	6.83E-07	5.00E-08	4.87E-08	1.23E-07	5.82E-07	1.40E-07	1.65E-07	5.96E-06	5.73E-07	4.58E-06
Change in SOC (%)	mean	3.79E+00	3.84E+00	4.58E+00	4.02E+00	3.69E+00	4.54E+00	4.83E+00	3.78E+00	4.55E+00	7.28E-01	1.09E+00	1.27E+00	2.22E+00	1.91E+00	2.23E+00	1.74E+00	3.82E+00	4.48E+00
	variance	2.85E+00	4.49E-01	9.40E-01	4.56E+00	4.00E-01	1.03E+00	4.55E+00	4.22E-01	1.01E+00	3.53E-02	3.47E-02	7.85E-02	4.67E-01	1.11E-01	2.34E-01	1.47E+00	4.61E-01	9.90E-01
Distance (km)		8.73E+02	8.09E+02	1.00E+03															

Intensity S2



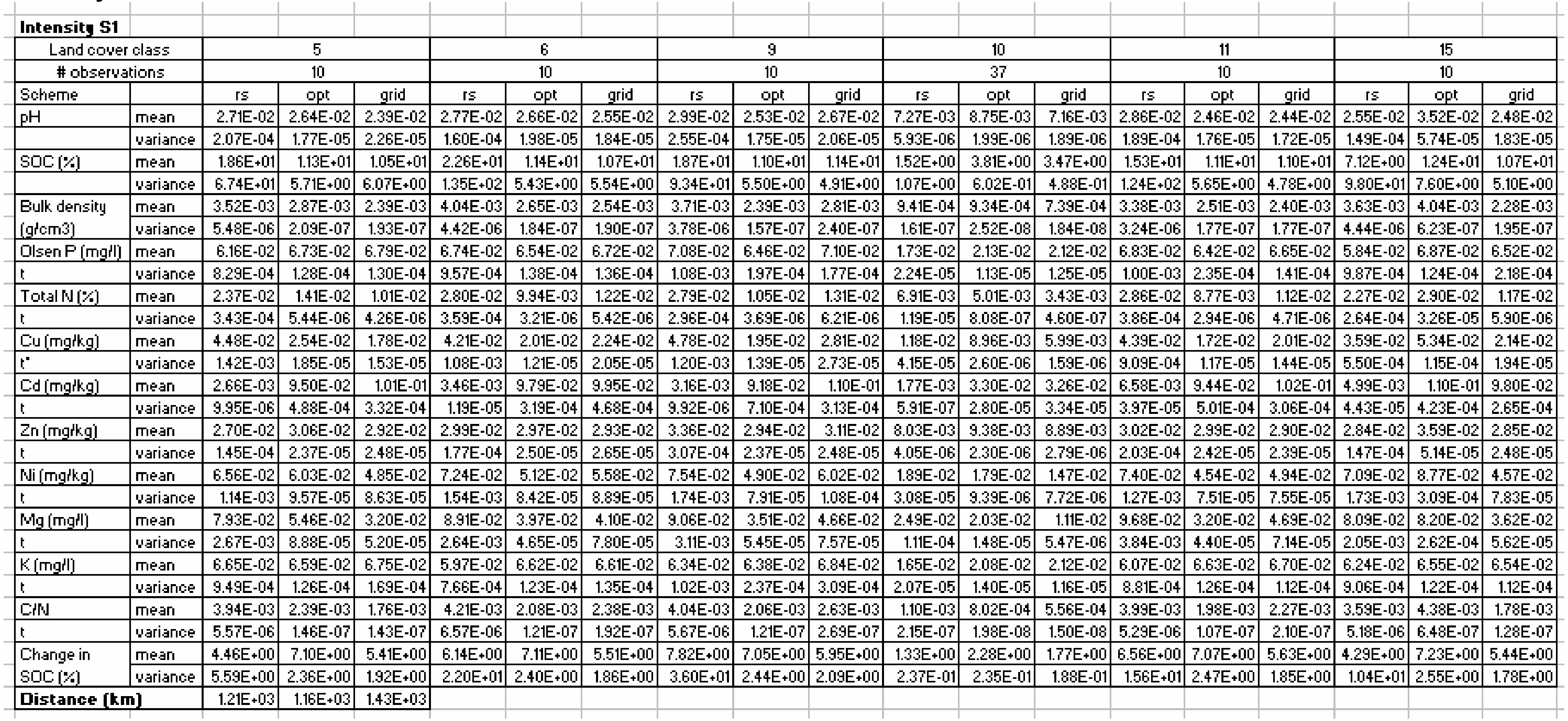
Intensity S2																			
Land cover class		6			8			9			10			11			15		
# observations		20			20			20			85			45			20		
Scheme		rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid
pH	mean	4.69E-02	5.24E-02	5.17E-02	4.75E-02	5.15E-02	5.27E-02	4.55E-02	5.32E-02	5.18E-02	1.18E-02	1.85E-02	1.66E-02	2.23E-02	2.92E-02	2.59E-02	4.46E-02	5.69E-02	5.13E-02
	variance	3.68E-04	2.79E-05	2.70E-05	2.94E-04	2.76E-05	2.77E-05	2.07E-04	2.83E-05	2.70E-05	6.18E-06	3.39E-06	3.44E-06	2.72E-05	9.11E-06	7.87E-06	2.29E-04	3.60E-05	2.82E-05
SOC (%)	mean	5.43E+00	1.61E+00	4.54E+00	1.79E+00	1.48E+00	3.72E+00	3.18E+00	1.58E+00	4.73E+00	2.57E-01	6.32E-01	1.37E+00	1.07E+00	8.93E-01	2.21E+00	1.29E+00	2.03E+00	3.68E+00
	variance	2.28E+01	1.27E+00	1.42E+00	5.28E+00	1.06E+00	7.38E-01	1.37E+01	1.25E+00	1.42E+00	4.68E-02	2.00E-01	1.21E-01	1.17E+00	3.87E-01	3.51E-01	3.91E+00	2.13E+00	7.12E-01
Bulk density (g/cm3)	mean	1.79E-03	1.45E-03	1.62E-03	2.05E-03	1.49E-03	1.40E-03	1.84E-03	1.66E-03	1.59E-03	4.56E-04	6.30E-04	4.54E-04	8.20E-04	8.87E-04	7.18E-04	1.86E-03	2.33E-03	1.34E-03
	variance	6.35E-07	2.23E-08	3.38E-08	1.17E-06	2.46E-08	2.71E-08	8.34E-07	2.82E-08	3.31E-08	3.02E-08	4.10E-09	2.58E-09	1.16E-07	8.35E-09	6.60E-09	9.73E-07	6.37E-08	2.70E-08
Olsen P (mg/l)	mean	2.77E-02	3.10E-02	2.85E-02	2.91E-02	2.92E-02	2.99E-02	2.64E-02	2.97E-02	3.06E-02	6.71E-03	1.03E-02	9.19E-03	1.22E-02	1.65E-02	1.43E-02	2.60E-02	3.37E-02	2.85E-02
t	variance	8.24E-05	9.65E-06	1.00E-05	1.04E-04	8.88E-06	9.38E-06	5.90E-05	9.03E-06	9.36E-06	1.69E-06	1.07E-06	1.07E-06	7.59E-06	2.72E-06	2.38E-06	8.40E-05	1.29E-05	9.31E-06
Total N (%)	mean	1.49E-02	1.61E-02	1.65E-02	1.36E-02	1.58E-02	1.62E-02	1.42E-02	1.63E-02	1.64E-02	3.42E-03	5.39E-03	5.19E-03	6.27E-03	8.60E-03	8.32E-03	1.45E-02	1.66E-02	1.59E-02
t	variance	2.85E-05	3.99E-06	3.32E-06	2.61E-05	2.96E-06	2.94E-06	2.51E-05	3.06E-06	2.97E-06	3.35E-07	3.03E-07	3.53E-07	1.99E-06	7.35E-07	7.36E-07	2.55E-05	3.73E-06	2.86E-06
Cu (mg/kg)	mean	1.22E-02	1.48E-02	1.47E-02	1.38E-02	1.40E-02	1.48E-02	1.26E-02	1.50E-02	1.48E-02	3.41E-03	5.22E-03	4.52E-03	6.05E-03	8.23E-03	7.05E-03	1.42E-02	1.62E-02	1.48E-02
t*	variance	2.04E-05	2.34E-06	2.25E-06	3.79E-05	2.14E-06	2.35E-06	2.15E-05	2.33E-06	2.24E-06	7.24E-07	2.74E-07	2.67E-07	3.26E-06	7.37E-07	5.89E-07	3.13E-05	2.86E-06	2.39E-06
Cd (mg/kg)	mean	3.69E-03	3.54E-03	3.49E-03	3.79E-03	3.36E-03	3.38E-03	3.71E-03	3.60E-03	3.51E-03	8.95E-04	1.35E-03	1.03E-03	1.70E-03	2.00E-03	1.66E-03	3.72E-03	4.21E-03	3.16E-03
t	variance	2.27E-06	1.37E-07	1.39E-07	2.65E-06	1.33E-07	1.45E-07	2.16E-06	1.36E-07	1.45E-07	4.76E-08	1.95E-08	1.39E-08	2.40E-07	3.96E-08	3.30E-08	2.29E-06	1.84E-07	1.51E-07
Zn (mg/kg)	mean	1.32E-02	1.46E-02	1.41E-02	1.40E-02	1.39E-02	1.39E-02	1.40E-02	1.41E-02	1.44E-02	3.43E-03	4.87E-03	4.35E-03	6.56E-03	7.79E-03	6.74E-03	1.38E-02	1.54E-02	1.44E-02
t	variance	3.05E-05	2.18E-06	2.12E-06	2.32E-05	2.03E-06	2.17E-06	2.17E-05	2.05E-06	2.09E-06	5.16E-07	2.33E-07	2.42E-07	2.65E-06	6.66E-07	5.47E-07	2.04E-05	2.63E-06	2.20E-06
Ni (mg/kg)	mean	1.89E-02	2.04E-02	1.99E-02	1.85E-02	1.97E-02	1.97E-02	1.86E-02	2.03E-02	2.01E-02	4.51E-03	6.84E-03	6.61E-03	7.99E-03	1.15E-02	9.93E-03	1.93E-02	2.15E-02	2.00E-02
t	variance	6.14E-05	4.21E-06	4.20E-06	4.43E-05	4.04E-06	4.07E-06	4.82E-05	4.14E-06	4.05E-06	9.56E-07	4.59E-07	5.24E-07	5.05E-06	1.41E-06	1.13E-06	4.26E-05	4.88E-06	4.36E-06
Mg (mg/l)	mean	2.52E-02	2.40E-02	2.45E-02	2.64E-02	2.36E-02	2.38E-02	2.63E-02	2.43E-02	2.49E-02	6.30E-03	8.31E-03	7.29E-03	1.17E-02	1.32E-02	1.17E-02	2.70E-02	2.94E-02	2.40E-02
t	variance	1.13E-04	6.30E-06	6.55E-06	9.20E-05	6.01E-06	7.15E-06	1.39E-04	6.22E-06	6.46E-06	2.98E-06	6.87E-07	6.62E-07	1.72E-05	1.87E-06	1.53E-06	1.53E-04	1.06E-05	7.28E-06
K (mg/l)	mean	1.68E-02	1.88E-02	1.81E-02	1.69E-02	1.81E-02	1.83E-02	1.80E-02	1.84E-02	1.83E-02	4.15E-03	6.23E-03	5.91E-03	7.55E-03	1.05E-02	9.02E-03	1.76E-02	2.09E-02	1.80E-02
t	variance	3.90E-05	3.57E-06	3.45E-06	4.27E-05	3.43E-06	3.39E-06	3.65E-05	3.48E-06	3.37E-06	6.00E-07	4.02E-07	4.09E-07	3.00E-06	1.14E-06	9.15E-07	4.66E-05	4.95E-06	3.37E-06
C/N	mean	2.46E-03	2.85E-03	2.90E-03	2.43E-03	2.76E-03	2.90E-03	2.46E-03	2.78E-03	2.92E-03	6.00E-04	9.27E-04	9.14E-04	1.08E-03	1.47E-03	1.46E-03	2.49E-03	2.88E-03	2.80E-03
t	variance	5.43E-07	9.03E-08	1.36E-07	4.95E-07	1.72E-07	8.30E-08	6.92E-07	1.19E-07	9.35E-08	7.57E-09	9.05E-09	1.03E-08	5.29E-08	2.11E-08	2.18E-08	5.50E-07	8.85E-08	9.14E-08
Change in SOC (%)	mean	1.94E+00	2.04E+00	2.56E+00	2.01E+00	1.98E+00	2.53E+00	2.39E+00	2.02E+00	2.60E+00	3.64E-01	6.82E-01	8.13E-01	1.10E+00	1.06E+00	1.28E+00	8.88E-01	2.16E+00	2.48E+00
	variance	4.34E-01	5.17E-02	1.13E-01	4.35E-01	4.52E-02	1.13E-01	1.23E+00	5.02E-02	1.15E-01	6.80E-03	6.11E-03	1.10E-02	5.25E-02	1.37E-02	2.72E-02	2.00E-01	7.13E-02	1.11E-01
Distance (km)		1.21E+03	1.10E+03	1.51E+03															

Intensity S3

Intensity S3																									
Land cover class		6				8				9				10				11				15			
# observations		40				40				40				170				89				40			
Scheme		rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust
pH	mean	2.26E-02	3.02E-02	2.78E-02	3.50E-02	2.43E-02	2.91E-02	2.90E-02	3.63E-02	2.38E-02	2.98E-02	2.88E-02	3.72E-02	5.79E-03	1.22E-02	1.14E-02	8.76E-03	1.09E-02	1.80E-02	1.59E-02	1.66E-02	2.50E-02	3.16E-02	2.81E-02	3.28E-02
	variance	2.71E-05	4.46E-06	4.12E-06	4.17E-04	2.89E-05	4.15E-06	4.25E-06	3.68E-04	3.47E-05	4.49E-06	4.11E-06	5.15E-04	6.23E-07	8.10E-07	8.12E-07	8.66E-06	4.73E-06	1.93E-06	1.30E-06	6.14E-05	4.05E-05	5.44E-06	5.13E-06	3.89E-04
SOC (%)	mean	2.61E+00	1.26E+00	2.39E+00	4.11E+00	1.04E+00	1.25E+00	2.73E+00	1.80E+00	1.25E+00	1.37E+00	2.68E+00	2.19E+00	1.39E-01	6.45E-01	1.22E+00	2.18E-01	5.51E-01	7.81E-01	1.66E+00	9.31E-01	5.21E-01	1.57E+00	2.36E+00	9.90E-01
	variance	5.33E+00	2.07E-01	2.14E-01	1.92E+01	1.69E+00	2.06E-01	2.71E-01	3.93E+00	1.87E+00	2.44E-01	2.60E-01	8.62E+00	7.54E-03	5.75E-02	6.25E-02	2.35E-02	2.14E-01	8.18E-02	1.07E-01	1.46E+00	2.36E-01	2.98E-01	2.18E-01	2.46E+00
Bulk density	mean	8.59E-04	7.66E-04	6.46E-04	2.70E-03	8.27E-04	7.30E-04	6.46E-04	2.93E-03	8.52E-04	8.28E-04	6.68E-04	2.70E-03	2.15E-04	4.22E-04	3.04E-04	7.05E-04	3.93E-04	4.66E-04	3.87E-04	1.20E-03	8.05E-04	9.98E-04	6.68E-04	2.80E-03
(g/cm3)	variance	1.26E-07	2.89E-09	2.35E-09	3.58E-06	8.95E-08	2.76E-09	2.41E-09	4.52E-06	1.08E-07	3.27E-09	2.50E-09	3.80E-06	3.47E-09	9.11E-10	5.16E-10	9.03E-08	2.07E-08	1.37E-09	8.30E-10	2.71E-07	8.39E-08	5.71E-09	3.51E-09	2.85E-06
Olsen P (mg/l)	mean	1.37E-02	1.66E-02	1.56E-02	2.21E-02	1.40E-02	1.62E-02	1.58E-02	2.36E-02	1.33E-02	1.65E-02	1.60E-02	2.25E-02	3.28E-03	7.03E-03	6.36E-03	5.62E-03	6.21E-03	1.03E-02	8.91E-03	1.05E-02	1.37E-02	1.83E-02	1.55E-02	2.26E-02
t	variance	1.56E-05	1.39E-06	1.27E-06	1.33E-04	1.12E-05	1.31E-06	1.38E-06	1.67E-04	1.30E-05	1.34E-06	1.28E-06	1.47E-04	1.93E-07	2.47E-07	2.04E-07	3.58E-06	1.11E-06	5.51E-07	4.05E-07	1.45E-05	1.22E-05	1.65E-06	1.30E-06	1.43E-04
Total N (%)	mean	7.24E-03	8.70E-03	8.11E-03	1.88E-02	7.02E-03	8.86E-03	8.36E-03	1.59E-02	7.45E-03	9.05E-03	9.15E-03	1.73E-02	1.71E-03	3.83E-03	3.56E-03	4.17E-03	3.26E-03	5.07E-03	5.08E-03	7.97E-03	7.24E-03	9.37E-03	8.23E-03	1.75E-02
t	variance	3.36E-06	4.99E-07	6.73E-07	9.70E-05	3.24E-06	3.91E-07	6.88E-07	6.05E-05	3.16E-06	4.24E-07	4.22E-07	8.30E-05	5.08E-08	7.54E-08	6.83E-08	9.58E-07	3.96E-07	1.30E-07	1.41E-07	7.51E-06	2.67E-06	5.21E-07	6.15E-07	6.44E-05
Cu (mg/kg)	mean	6.11E-03	8.33E-03	7.54E-03	1.31E-02	6.84E-03	7.88E-03	7.59E-03	1.44E-02	6.18E-03	8.49E-03	7.77E-03	1.25E-02	1.63E-03	3.71E-03	3.16E-03	3.55E-03	2.91E-03	4.99E-03	4.39E-03	6.12E-03	6.76E-03	9.07E-03	7.76E-03	1.36E-02
t"	variance	2.85E-06	3.56E-07	3.14E-07	7.10E-05	4.60E-06	3.14E-07	3.30E-07	8.39E-05	2.69E-06	3.67E-07	3.19E-07	5.20E-05	1.20E-07	7.37E-08	6.05E-08	2.17E-06	4.02E-07	1.72E-07	1.02E-07	8.46E-06	4.74E-06	4.40E-07	4.17E-07	9.34E-05
Cd (mg/kg)	mean	1.86E-03	1.88E-03	1.60E-03	5.01E-03	1.92E-03	1.76E-03	1.70E-03	5.16E-03	1.87E-03	1.91E-03	1.82E-03	5.18E-03	4.61E-04	8.88E-04	6.75E-04	1.22E-03	8.54E-04	1.13E-03	9.64E-04	2.36E-03	1.84E-03	2.10E-03	1.66E-03	4.95E-03
t	variance	4.51E-07	1.78E-08	1.54E-08	1.33E-05	3.20E-07	1.73E-08	1.62E-08	9.05E-06	3.43E-07	1.79E-08	1.75E-08	7.82E-06	1.17E-08	3.94E-09	2.52E-09	2.77E-07	5.27E-08	6.13E-09	4.95E-09	1.53E-06	3.08E-07	2.21E-08	1.67E-08	5.48E-06
Zn (mg/kg)	mean	7.18E-03	8.56E-03	7.11E-03	1.27E-02	7.39E-03	7.54E-03	7.41E-03	1.31E-02	7.23E-03	7.98E-03	7.47E-03	1.31E-02	1.73E-03	3.31E-03	2.98E-03	3.17E-03	3.20E-03	4.83E-03	4.09E-03	6.15E-03	6.94E-03	8.54E-03	7.31E-03	1.19E-02
t	variance	3.41E-06	3.54E-07	2.92E-07	6.12E-05	6.44E-06	2.85E-07	3.03E-07	7.70E-05	3.84E-06	3.11E-07	2.82E-07	7.12E-05	9.99E-08	5.61E-08	5.28E-08	1.27E-06	4.15E-07	1.34E-07	9.08E-08	7.25E-06	3.32E-06	3.83E-07	3.56E-07	4.60E-05
Ni (mg/kg)	mean	9.72E-03	1.15E-02	1.06E-02	1.36E-02	9.46E-03	1.12E-02	1.09E-02	1.49E-02	9.72E-03	1.18E-02	1.09E-02	1.41E-02	2.34E-03	4.60E-03	4.45E-03	3.45E-03	4.26E-03	6.98E-03	6.19E-03	6.29E-03	9.65E-03	1.26E-02	1.09E-02	1.44E-02
t	variance	7.49E-06	7.00E-07	6.17E-07	6.23E-05	7.19E-06	6.25E-07	6.20E-07	8.75E-05	6.33E-06	7.12E-07	6.02E-07	5.80E-05	1.44E-07	1.08E-07	1.24E-07	1.62E-06	5.89E-07	3.28E-07	2.06E-07	5.61E-06	5.77E-06	9.23E-07	9.22E-07	6.26E-05
Mg (mg/l)	mean	1.32E-02	1.30E-02	1.18E-02	2.70E-02	1.37E-02	1.26E-02	1.22E-02	2.79E-02	1.32E-02	1.40E-02	1.31E-02	2.97E-02	3.26E-03	6.17E-03	4.90E-03	7.43E-03	5.94E-03	8.46E-03	6.88E-03	1.28E-02	1.24E-02	1.48E-02	1.19E-02	2.78E-02
t	variance	2.29E-05	8.92E-07	8.02E-07	3.55E-04	2.29E-05	8.28E-07	8.10E-07	2.55E-04	1.83E-05	9.72E-07	8.54E-07	2.79E-04	4.96E-07	1.96E-07	1.38E-07	7.51E-06	2.95E-06	4.18E-07	2.53E-07	2.75E-05	2.08E-05	1.14E-06	9.00E-07	2.73E-04
K (mg/l)	mean	8.46E-03	1.05E-02	9.66E-03	1.41E-02	8.75E-03	1.01E-02	1.00E-02	1.45E-02	8.50E-03	1.08E-02	9.97E-03	1.31E-02	2.07E-03	4.31E-03	4.16E-03	3.27E-03	3.74E-03	6.51E-03	5.78E-03	6.09E-03	8.32E-03	1.22E-02	9.93E-03	1.30E-02
t	variance	5.27E-06	5.46E-07	5.32E-07	6.71E-05	5.05E-06	5.02E-07	5.26E-07	6.19E-05	3.95E-06	5.81E-07	5.07E-07	3.50E-05	9.38E-08	9.69E-08	1.09E-07	9.12E-07	4.63E-07	2.66E-07	1.68E-07	6.47E-06	4.16E-06	9.31E-07	5.24E-07	5.56E-05
C/N	mean	1.29E-03	1.61E-03	1.59E-03	2.44E-03	1.27E-03	1.58E-03	1.57E-03	2.56E-03	1.26E-03	1.60E-03	1.59E-03	2.50E-03	2.98E-04	6.52E-04	6.31E-04	5.77E-04	5.68E-04	9.21E-04	8.82E-04	1.10E-03	1.29E-03	1.64E-03	1.51E-03	2.46E-03
t	variance	8.67E-08	1.26E-08	1.41E-08	1.31E-06	1.10E-07	1.22E-08	1.45E-08	1.48E-06	9.55E-08	1.37E-08	1.41E-08	1.35E-06	1.31E-09	2.21E-09	2.13E-09	1.82E-08	9.32E-09	4.17E-09	4.63E-09	1.27E-07	8.57E-08	1.56E-08	2.46E-08	1.58E-06
Change in	mean	1.02E+00	1.25E+00	1.49E+00	1.03E+00	1.04E+00	1.23E+00	1.52E+00	1.04E+00	1.17E+00	1.27E+00	1.55E+00	1.22E+00	1.89E-01	5.23E-01	6.21E-01	1.99E-01	5.83E-01	7.28E-01	8.78E-01	6.43E-01	4.35E-01	1.33E+00	1.48E+00	5.23E-01
SOC (%)	variance	7.27E-02	1.17E-02	1.35E-02	2.66E-01	5.86E-02	9.70E-03	1.62E-02	2.15E-01	7.06E-02	1.28E-02	1.74E-02	2.85E-01	8.15E-04	2.85E-03	3.41E-03	1.63E-03	8.74E-03	4.43E-03	6.23E-03	4.71E-02	2.12E-02	2.39E-02	1.37E-02	8.70E-02
Distance (km)		1.69E+03	1.59E+03	1.99E+03	9.23E+02																				

Northern Ireland

Intensity S1



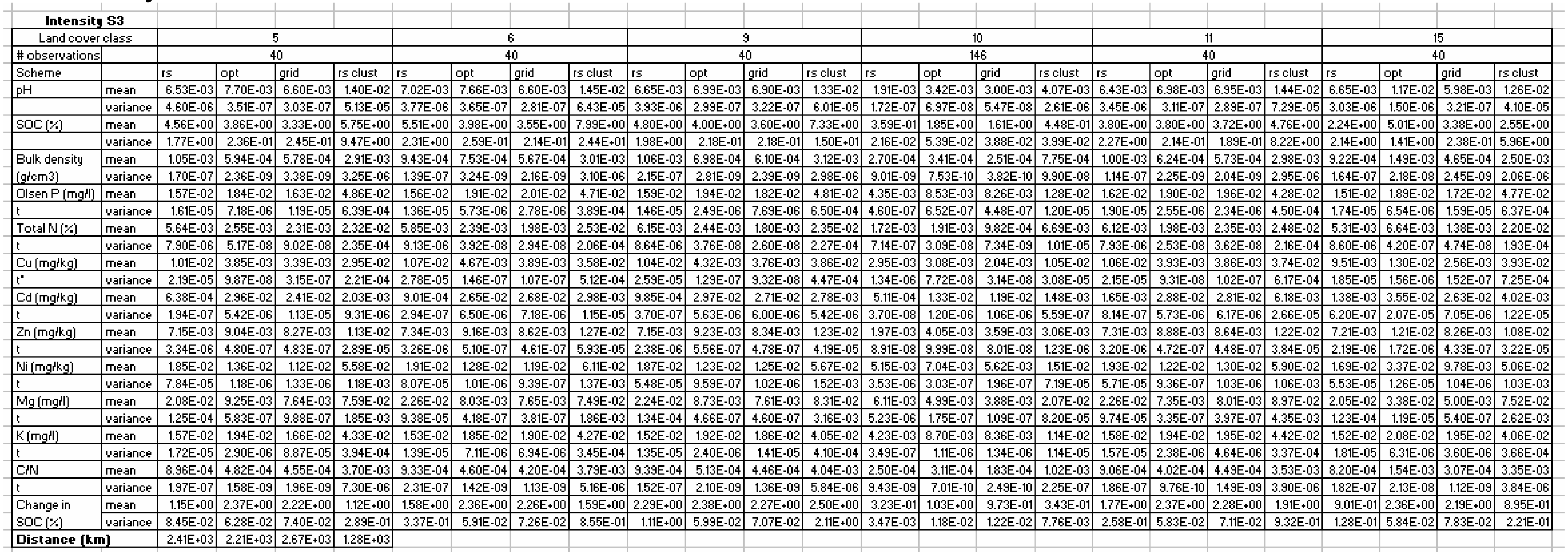
Intensity S1

Land cover class		5			6			9			10			11			15		
# observations		10			10			10			37			10			10		
Scheme		rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid
pH	mean	2.71E-02	2.64E-02	2.39E-02	2.77E-02	2.66E-02	2.55E-02	2.99E-02	2.53E-02	2.67E-02	7.27E-03	8.75E-03	7.16E-03	2.86E-02	2.46E-02	2.44E-02	2.55E-02	3.52E-02	2.48E-02
	variance	2.07E-04	1.77E-05	2.26E-05	1.60E-04	1.98E-05	1.84E-05	2.55E-04	1.75E-05	2.06E-05	5.93E-06	1.99E-06	1.89E-06	1.89E-04	1.76E-05	1.72E-05	1.49E-04	5.74E-05	1.83E-05
SOC (%)	mean	1.86E+01	1.13E+01	1.05E+01	2.26E+01	1.14E+01	1.07E+01	1.87E+01	1.10E+01	1.14E+01	1.52E+00	3.81E+00	3.47E+00	1.53E+01	1.11E+01	1.10E+01	7.12E+00	1.24E+01	1.07E+01
	variance	6.74E+01	5.71E+00	6.07E+00	1.35E+02	5.43E+00	5.54E+00	9.34E+01	5.50E+00	4.91E+00	1.07E+00	6.02E-01	4.88E-01	1.24E+02	5.65E+00	4.78E+00	9.80E+01	7.60E+00	5.10E+00
Bulk density (g/cm3)	mean	3.52E-03	2.87E-03	2.39E-03	4.04E-03	2.65E-03	2.54E-03	3.71E-03	2.39E-03	2.81E-03	9.41E-04	9.34E-04	7.39E-04	3.38E-03	2.51E-03	2.40E-03	3.63E-03	4.04E-03	2.28E-03
	variance	5.48E-06	2.09E-07	1.93E-07	4.42E-06	1.84E-07	1.90E-07	3.78E-06	1.57E-07	2.40E-07	1.61E-07	2.52E-08	1.84E-08	3.24E-06	1.77E-07	1.77E-07	4.44E-06	6.23E-07	1.95E-07
Olsen P (mg/l)	mean	6.16E-02	6.73E-02	6.79E-02	6.74E-02	6.54E-02	6.72E-02	7.08E-02	6.46E-02	7.10E-02	1.73E-02	2.13E-02	2.12E-02	6.83E-02	6.42E-02	6.65E-02	5.84E-02	6.87E-02	6.52E-02
t	variance	8.29E-04	1.28E-04	1.30E-04	9.57E-04	1.38E-04	1.36E-04	1.08E-03	1.97E-04	1.77E-04	2.24E-05	1.13E-05	1.25E-05	1.00E-03	2.35E-04	1.41E-04	9.87E-04	1.24E-04	2.18E-04
Total N (%)	mean	2.37E-02	1.41E-02	1.01E-02	2.80E-02	9.94E-03	1.22E-02	2.79E-02	1.05E-02	1.31E-02	6.91E-03	5.01E-03	3.43E-03	2.86E-02	8.77E-03	1.12E-02	2.27E-02	2.90E-02	1.17E-02
t	variance	3.43E-04	5.44E-06	4.26E-06	3.59E-04	3.21E-06	5.42E-06	2.96E-04	3.69E-06	6.21E-06	1.19E-05	8.08E-07	4.60E-07	3.86E-04	2.94E-06	4.71E-06	2.64E-04	3.26E-05	5.90E-06
Cu (mg/kg)	mean	4.48E-02	2.54E-02	1.78E-02	4.21E-02	2.01E-02	2.24E-02	4.78E-02	1.95E-02	2.81E-02	1.18E-02	8.96E-03	5.99E-03	4.39E-02	1.72E-02	2.01E-02	3.59E-02	5.34E-02	2.14E-02
t'	variance	1.42E-03	1.85E-05	1.53E-05	1.08E-03	1.21E-05	2.05E-05	1.20E-03	1.39E-05	2.73E-05	4.15E-05	2.60E-06	1.59E-06	9.09E-04	1.17E-05	1.44E-05	5.50E-04	1.15E-04	1.94E-05
Cd (mg/kg)	mean	2.66E-03	9.50E-02	1.01E-01	3.46E-03	9.79E-02	9.95E-02	3.16E-03	9.18E-02	1.10E-01	1.77E-03	3.30E-02	3.26E-02	6.58E-03	9.44E-02	1.02E-01	4.99E-03	1.10E-01	9.80E-02
t	variance	9.95E-06	4.88E-04	3.32E-04	1.19E-05	3.19E-04	4.68E-04	9.92E-06	7.10E-04	3.13E-04	5.91E-07	2.80E-05	3.34E-05	3.97E-05	5.01E-04	3.06E-04	4.43E-05	4.23E-04	2.65E-04
Zn (mg/kg)	mean	2.70E-02	3.06E-02	2.92E-02	2.99E-02	2.97E-02	2.93E-02	3.36E-02	2.94E-02	3.11E-02	8.03E-03	9.38E-03	8.89E-03	3.02E-02	2.99E-02	2.90E-02	2.84E-02	3.59E-02	2.85E-02
t	variance	1.45E-04	2.37E-05	2.48E-05	1.77E-04	2.50E-05	2.65E-05	3.07E-04	2.37E-05	2.48E-05	4.05E-06	2.30E-06	2.79E-06	2.03E-04	2.42E-05	2.39E-05	1.47E-04	5.14E-05	2.48E-05
Ni (mg/kg)	mean	6.56E-02	6.03E-02	4.85E-02	7.24E-02	5.12E-02	5.58E-02	7.54E-02	4.90E-02	6.02E-02	1.89E-02	1.79E-02	1.47E-02	7.40E-02	4.54E-02	4.94E-02	7.09E-02	8.77E-02	4.57E-02
t	variance	1.14E-03	9.57E-05	8.63E-05	1.54E-03	8.42E-05	8.89E-05	1.74E-03	7.91E-05	1.08E-04	3.08E-05	9.39E-06	7.72E-06	1.27E-03	7.51E-05	7.55E-05	1.73E-03	3.09E-04	7.83E-05
Mg (mg/l)	mean	7.93E-02	5.46E-02	3.20E-02	8.91E-02	3.97E-02	4.10E-02	9.06E-02	3.51E-02	4.66E-02	2.49E-02	2.03E-02	1.11E-02	9.68E-02	3.20E-02	4.69E-02	8.09E-02	8.20E-02	3.62E-02
t	variance	2.67E-03	8.88E-05	5.20E-05	2.64E-03	4.65E-05	7.80E-05	3.11E-03	5.45E-05	7.57E-05	1.11E-04	1.48E-05	5.47E-06	3.84E-03	4.40E-05	7.14E-05	2.05E-03	2.62E-04	5.62E-05
K (mg/l)	mean	6.65E-02	6.59E-02	6.75E-02	5.97E-02	6.62E-02	6.61E-02	6.34E-02	6.38E-02	6.84E-02	1.65E-02	2.08E-02	2.12E-02	6.07E-02	6.63E-02	6.70E-02	6.24E-02	6.55E-02	6.54E-02
t	variance	9.49E-04	1.26E-04	1.69E-04	7.66E-04	1.23E-04	1.35E-04	1.02E-03	2.37E-04	3.09E-04	2.07E-05	1.40E-05	1.16E-05	8.81E-04	1.26E-04	1.12E-04	9.06E-04	1.22E-04	1.12E-04
C/N	mean	3.94E-03	2.39E-03	1.76E-03	4.21E-03	2.08E-03	2.38E-03	4.04E-03	2.06E-03	2.63E-03	1.10E-03	8.02E-04	5.56E-04	3.99E-03	1.98E-03	2.27E-03	3.59E-03	4.38E-03	1.78E-03
t	variance	5.57E-06	1.46E-07	1.43E-07	6.57E-06	1.21E-07	1.92E-07	5.67E-06	1.21E-07	2.69E-07	2.15E-07	1.98E-08	1.50E-08	5.29E-06	1.07E-07	2.10E-07	5.18E-06	6.48E-07	1.28E-07
Change in SOC (%)	mean	4.46E+00	7.10E+00	5.41E+00	6.14E+00	7.11E+00	5.51E+00	7.82E+00	7.05E+00	5.95E+00	1.33E+00	2.28E+00	1.77E+00	6.56E+00	7.07E+00	5.63E+00	4.29E+00	7.23E+00	5.44E+00
	variance	5.59E+00	2.36E+00	1.92E+00	2.20E+01	2.40E+00	1.86E+00	3.60E+01	2.44E+00	2.09E+00	2.37E-01	2.35E-01	1.88E-01	1.56E+01	2.47E+00	1.85E+00	1.04E+01	2.55E+00	1.78E+00
Distance (km)		1.21E+03	1.16E+03	1.43E+03															

Intensity S2

Intensity S2																			
Land cover class		5			6			9			10			11			15		
# observations		20			20			20			73			20			20		
Scheme		rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid	rs	opt	grid
pH	mean	1.38E-02	1.39E-02	1.32E-02	1.40E-02	1.35E-02	1.24E-02	1.33E-02	1.35E-02	1.25E-02	3.68E-03	5.68E-03	4.41E-03	1.44E-02	1.31E-02	1.22E-02	1.24E-02	1.93E-02	1.15E-02
	variance	1.85E-05	2.34E-06	3.09E-06	3.65E-05	2.27E-06	2.32E-06	3.16E-05	2.28E-06	2.14E-06	8.90E-07	4.20E-07	2.72E-07	2.34E-05	2.22E-06	2.05E-06	2.02E-05	8.06E-06	2.54E-06
SOC (%)	mean	9.46E+00	6.50E+00	5.73E+00	1.07E+01	6.56E+00	6.01E+00	9.95E+00	6.49E+00	5.88E+00	7.54E-01	2.43E+00	2.14E+00	7.23E+00	6.35E+00	5.88E+00	3.96E+00	7.08E+00	5.34E+00
	variance	1.23E+01	9.13E-01	9.87E-01	1.83E+01	8.90E-01	9.10E-01	1.09E+01	9.07E-01	1.02E+00	1.38E-01	1.38E-01	1.16E-01	1.45E+01	9.25E-01	9.43E-01	1.44E+01	2.36E+00	9.68E-01
Bulk density (g/cm3)	mean	1.50E-03	1.51E-03	1.13E-03	1.62E-03	1.37E-03	1.13E-03	1.72E-03	1.37E-03	1.13E-03	4.61E-04	5.59E-04	3.86E-04	1.67E-03	1.15E-03	1.14E-03	1.68E-03	2.76E-03	9.57E-04
	variance	4.14E-07	2.94E-08	2.42E-08	6.05E-07	2.41E-08	2.29E-08	6.33E-07	2.19E-08	1.90E-08	2.76E-08	3.67E-09	2.31E-09	3.54E-07	1.71E-08	1.78E-08	5.08E-07	1.86E-07	2.06E-08
Olsen P (mg/l)	mean	3.18E-02	3.56E-02	3.35E-02	3.16E-02	3.38E-02	3.60E-02	3.03E-02	3.56E-02	3.50E-02	8.33E-03	1.27E-02	1.29E-02	3.20E-02	3.49E-02	3.46E-02	2.84E-02	3.53E-02	3.05E-02
t	variance	1.28E-04	1.58E-05	4.31E-05	1.12E-04	3.22E-05	2.50E-05	9.90E-05	1.65E-05	2.12E-05	3.10E-06	2.39E-06	2.32E-06	1.04E-04	1.68E-05	2.51E-05	1.03E-04	2.59E-05	1.39E-04
Total N (%)	mean	1.09E-02	7.64E-03	4.40E-03	1.23E-02	7.06E-03	4.85E-03	1.23E-02	5.60E-03	4.44E-03	3.40E-03	3.08E-03	1.59E-03	1.22E-02	4.84E-03	4.35E-03	1.06E-02	1.12E-02	2.95E-03
t	variance	3.84E-05	8.24E-07	3.57E-07	4.37E-05	6.30E-07	3.90E-07	4.90E-05	4.08E-07	3.43E-07	2.46E-06	1.24E-07	4.32E-08	4.09E-05	3.04E-07	3.09E-07	4.40E-05	2.29E-06	2.48E-07
Cu (mg/kg)	mean	2.27E-02	1.48E-02	7.35E-03	2.36E-02	1.15E-02	8.81E-03	2.27E-02	9.52E-03	7.78E-03	6.26E-03	5.45E-03	3.13E-03	2.35E-02	8.69E-03	8.34E-03	1.95E-02	2.30E-02	5.88E-03
t"	variance	1.39E-04	3.14E-06	1.24E-06	1.51E-04	1.75E-06	1.21E-06	1.01E-04	1.31E-06	1.00E-06	7.34E-06	3.96E-07	1.57E-07	1.45E-04	1.00E-06	1.11E-06	9.99E-05	1.13E-05	9.42E-07
Cd (mg/kg)	mean	1.22E-03	5.15E-02	5.21E-02	1.62E-03	5.37E-02	5.32E-02	2.04E-03	5.01E-02	5.39E-02	9.44E-04	2.03E-02	1.91E-02	4.07E-03	4.84E-02	5.24E-02	2.92E-03	5.26E-02	4.68E-02
t	variance	7.36E-07	3.47E-05	4.33E-05	1.30E-06	3.92E-05	3.94E-05	1.97E-06	5.97E-05	4.67E-05	1.45E-07	5.05E-06	5.81E-06	1.09E-05	5.32E-05	4.15E-05	3.89E-06	8.29E-05	6.62E-05
Zn (mg/kg)	mean	1.52E-02	1.65E-02	1.60E-02	1.50E-02	1.64E-02	1.58E-02	1.51E-02	1.59E-02	1.53E-02	3.98E-03	6.14E-03	5.42E-03	1.60E-02	1.56E-02	1.50E-02	1.41E-02	2.00E-02	1.49E-02
t	variance	2.86E-05	3.37E-06	3.19E-06	2.47E-05	3.32E-06	3.19E-06	2.07E-05	3.15E-06	3.08E-06	5.43E-07	4.51E-07	3.97E-07	2.53E-05	3.08E-06	3.06E-06	3.77E-05	7.68E-06	3.55E-06
Ni (mg/kg)	mean	3.40E-02	3.26E-02	2.31E-02	3.77E-02	2.80E-02	2.41E-02	3.97E-02	2.78E-02	2.28E-02	9.99E-03	1.15E-02	7.81E-03	3.75E-02	2.47E-02	2.46E-02	3.55E-02	5.92E-02	1.87E-02
t	variance	2.02E-04	1.36E-05	1.13E-05	2.47E-04	1.01E-05	8.87E-06	4.16E-04	9.71E-06	8.27E-06	1.27E-05	1.70E-06	9.55E-07	2.18E-04	8.33E-06	8.32E-06	2.13E-04	9.48E-05	8.90E-06
Mg (mg/l)	mean	4.17E-02	3.27E-02	1.55E-02	4.08E-02	2.51E-02	1.86E-02	4.48E-02	2.05E-02	1.59E-02	1.12E-02	1.06E-02	5.55E-03	4.41E-02	1.93E-02	1.56E-02	3.73E-02	6.69E-02	9.25E-03
t	variance	4.96E-04	1.63E-05	4.89E-06	4.80E-04	8.42E-06	5.39E-06	5.68E-04	5.68E-06	4.35E-06	2.46E-05	1.63E-06	5.08E-07	4.93E-04	4.92E-06	4.26E-06	3.32E-04	1.17E-04	3.08E-06
K (mg/l)	mean	2.96E-02	3.37E-02	3.55E-02	3.18E-02	3.53E-02	3.44E-02	3.19E-02	3.45E-02	3.58E-02	8.33E-03	1.26E-02	1.26E-02	3.25E-02	3.41E-02	3.54E-02	2.97E-02	3.37E-02	3.35E-02
t	variance	1.03E-04	1.07E-04	8.37E-05	1.04E-04	4.80E-05	9.23E-05	1.28E-04	4.05E-05	1.70E-05	3.19E-06	2.16E-06	3.02E-06	1.12E-04	2.64E-05	1.98E-05	9.82E-05	6.60E-05	3.04E-05
C/N	mean	2.00E-03	1.34E-03	8.98E-04	2.01E-03	1.41E-03	9.02E-04	2.08E-03	1.19E-03	8.33E-04	5.36E-04	5.60E-04	3.17E-04	2.06E-03	7.76E-04	9.14E-04	1.84E-03	2.85E-03	6.47E-04
t	variance	9.20E-07	2.45E-08	1.69E-08	1.02E-06	2.65E-08	1.56E-08	1.28E-06	1.72E-08	1.18E-08	4.13E-08	4.42E-09	1.70E-09	1.17E-06	8.94E-09	1.49E-08	1.11E-06	1.70E-07	1.06E-08
Change in SOC (%)	mean	2.36E+00	3.37E+00	4.12E+00	3.38E+00	3.47E+00	4.13E+00	4.12E+00	3.40E+00	4.10E+00	6.50E-01	1.29E+00	1.48E+00	3.62E+00	3.30E+00	4.11E+00	2.08E+00	3.63E+00	4.03E+00
	variance	7.15E-01	1.88E-01	5.34E-01	4.01E+00	2.25E-01	5.23E-01	4.89E+00	1.92E-01	5.20E-01	2.73E-02	3.44E-02	6.68E-02	2.69E+00	1.37E-01	5.21E-01	1.86E+00	3.75E-01	5.02E-01
Distance (km)		1.71E+03	1.72E+03	1.96E+03															

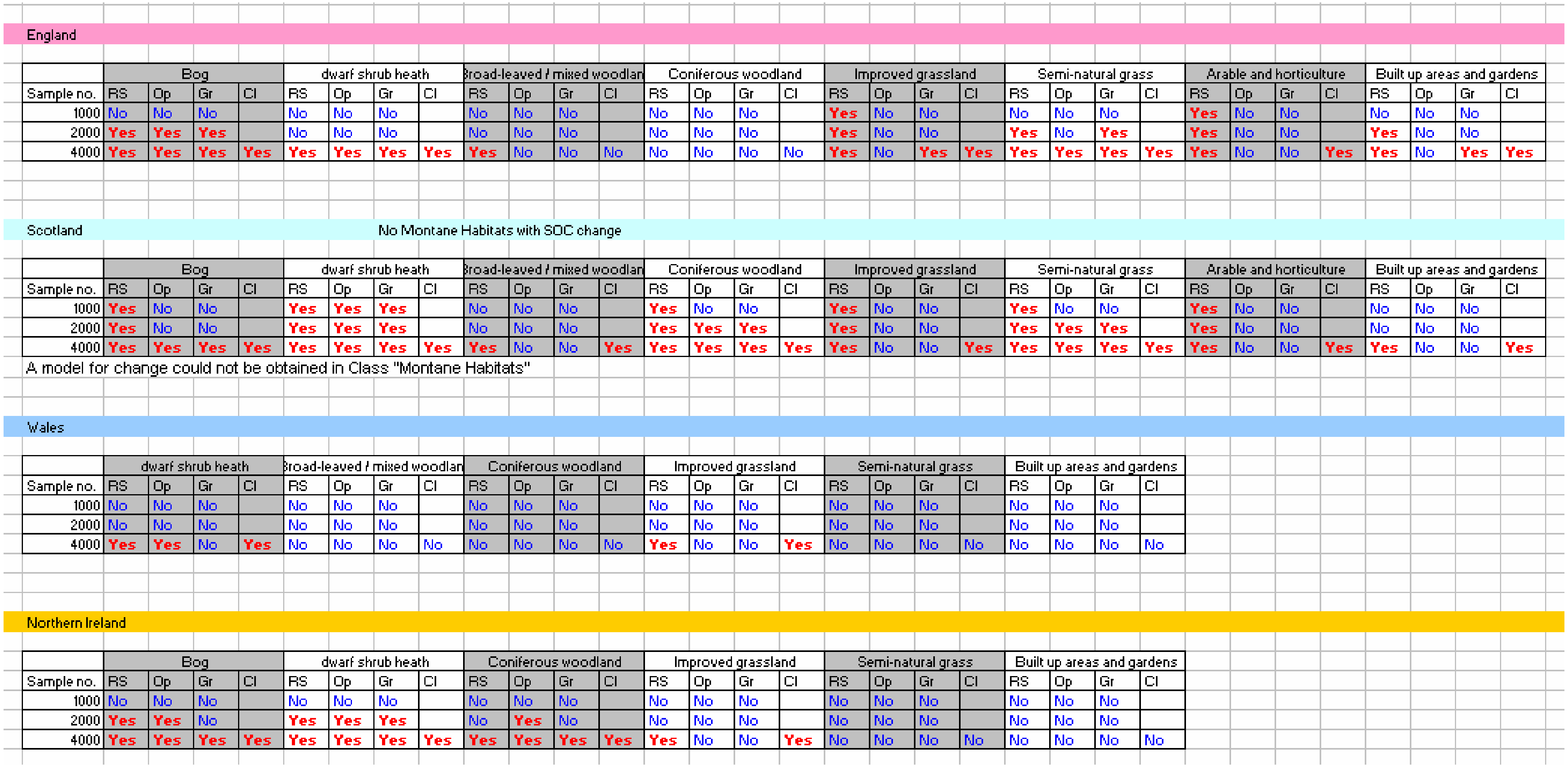
Intensity S3



Intensity S3																									
Land cover class		5				6				9				10				11				15			
# observations		40				40				40				146				40				40			
Scheme		rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust	rs	opt	grid	rs clust
pH	mean	6.53E-03	7.70E-03	6.60E-03	1.40E-02	7.02E-03	7.66E-03	6.60E-03	1.45E-02	6.65E-03	6.99E-03	6.90E-03	1.33E-02	1.91E-03	3.42E-03	3.00E-03	4.07E-03	6.43E-03	6.98E-03	6.95E-03	1.44E-02	6.65E-03	1.17E-02	5.98E-03	1.26E-02
	variance	4.60E-06	3.51E-07	3.03E-07	5.13E-05	3.77E-06	3.65E-07	2.81E-07	6.43E-05	3.93E-06	2.99E-07	3.22E-07	6.01E-05	1.72E-07	6.97E-08	5.47E-08	2.61E-06	3.45E-06	3.11E-07	2.89E-07	7.29E-05	3.03E-06	1.50E-06	3.21E-07	4.10E-05
SOC (%)	mean	4.56E+00	3.86E+00	3.33E+00	5.75E+00	5.51E+00	3.98E+00	3.55E+00	7.99E+00	4.80E+00	4.00E+00	3.60E+00	7.33E+00	3.59E-01	1.85E+00	1.61E+00	4.48E-01	3.80E+00	3.80E+00	3.72E+00	4.76E+00	2.24E+00	5.01E+00	3.38E+00	2.55E+00
	variance	1.77E+00	2.36E-01	2.45E-01	9.47E+00	2.31E+00	2.59E-01	2.14E-01	2.44E+01	1.98E+00	2.18E-01	2.18E-01	1.50E+01	2.16E-02	5.39E-02	3.88E-02	3.99E-02	2.27E+00	2.14E-01	1.89E-01	8.22E+00	2.14E+00	1.41E+00	2.38E-01	5.96E+00
Bulk density (g/cm3)	mean	1.05E-03	5.94E-04	5.78E-04	2.91E-03	9.43E-04	7.53E-04	5.67E-04	3.01E-03	1.06E-03	6.98E-04	6.10E-04	3.12E-03	2.70E-04	3.41E-04	2.51E-04	7.75E-04	1.00E-03	6.24E-04	5.73E-04	2.98E-03	9.22E-04	1.49E-03	4.65E-04	2.50E-03
	variance	1.70E-07	2.36E-09	3.38E-09	3.25E-06	1.39E-07	3.24E-09	2.16E-09	3.10E-06	2.15E-07	2.81E-09	2.39E-09	2.98E-06	9.01E-09	7.53E-10	3.82E-10	9.90E-08	1.14E-07	2.25E-09	2.04E-09	2.95E-06	1.64E-07	2.18E-08	2.45E-09	2.06E-06
Olsen P (mg/l)	mean	1.57E-02	1.84E-02	1.63E-02	4.86E-02	1.56E-02	1.91E-02	2.01E-02	4.71E-02	1.59E-02	1.94E-02	1.82E-02	4.81E-02	4.35E-03	8.53E-03	8.26E-03	1.28E-02	1.62E-02	1.90E-02	1.96E-02	4.28E-02	1.51E-02	1.89E-02	1.72E-02	4.77E-02
t	variance	1.61E-05	7.18E-06	1.19E-05	6.39E-04	1.36E-05	5.73E-06	2.78E-06	3.89E-04	1.46E-05	2.49E-06	7.69E-06	6.50E-04	4.60E-07	6.52E-07	4.48E-07	1.20E-05	1.90E-05	2.55E-06	2.34E-06	4.50E-04	1.74E-05	6.54E-06	1.59E-05	6.37E-04
Total N (%)	mean	5.64E-03	2.55E-03	2.31E-03	2.32E-02	5.85E-03	2.39E-03	1.98E-03	2.53E-02	6.15E-03	2.44E-03	1.80E-03	2.35E-02	1.72E-03	1.91E-03	9.82E-04	6.69E-03	6.12E-03	1.98E-03	2.35E-03	2.48E-02	5.31E-03	6.64E-03	1.38E-03	2.20E-02
t	variance	7.90E-06	5.17E-08	9.02E-08	2.35E-04	9.13E-06	3.92E-08	2.94E-08	2.06E-04	8.64E-06	3.76E-08	2.60E-08	2.27E-04	7.14E-07	3.09E-08	7.34E-09	1.01E-05	7.93E-06	2.53E-08	3.62E-08	2.16E-04	8.60E-06	4.20E-07	4.74E-08	1.93E-04
Cu (mg/kg)	mean	1.01E-02	3.85E-03	3.39E-03	2.95E-02	1.07E-02	4.67E-03	3.89E-03	3.58E-02	1.04E-02	4.32E-03	3.76E-03	3.86E-02	2.95E-03	3.08E-03	2.04E-03	1.05E-02	1.06E-02	3.93E-03	3.86E-03	3.74E-02	9.51E-03	1.30E-02	2.56E-03	3.93E-02
t*	variance	2.19E-05	9.87E-08	3.15E-07	2.21E-04	2.78E-05	1.46E-07	1.07E-07	5.12E-04	2.59E-05	1.29E-07	9.32E-08	4.47E-04	1.34E-06	7.72E-08	3.14E-08	3.08E-05	2.15E-05	9.31E-08	1.02E-07	6.17E-04	1.85E-05	1.56E-06	1.52E-07	7.25E-04
Cd (mg/kg)	mean	6.38E-04	2.96E-02	2.41E-02	2.03E-03	9.01E-04	2.65E-02	2.68E-02	2.98E-03	9.85E-04	2.97E-02	2.71E-02	2.78E-03	5.11E-04	1.33E-02	1.19E-02	1.48E-03	1.65E-03	2.88E-02	2.81E-02	6.18E-03	1.38E-03	3.55E-02	2.63E-02	4.02E-03
t	variance	1.94E-07	5.42E-06	1.13E-05	9.31E-06	2.94E-07	6.50E-06	7.18E-06	1.15E-05	3.70E-07	5.63E-06	6.00E-06	5.42E-06	3.70E-08	1.20E-06	1.06E-06	5.59E-07	8.14E-07	5.73E-06	6.17E-06	2.66E-05	6.20E-07	2.07E-05	7.05E-06	1.22E-05
Zn (mg/kg)	mean	7.15E-03	9.04E-03	8.27E-03	1.13E-02	7.34E-03	9.16E-03	8.62E-03	1.27E-02	7.15E-03	9.23E-03	8.34E-03	1.23E-02	1.97E-03	4.05E-03	3.59E-03	3.06E-03	7.31E-03	8.88E-03	8.64E-03	1.22E-02	7.21E-03	1.21E-02	8.26E-03	1.08E-02
t	variance	3.34E-06	4.80E-07	4.83E-07	2.89E-05	3.26E-06	5.10E-07	4.61E-07	5.93E-05	2.38E-06	5.56E-07	4.78E-07	4.19E-05	8.91E-08	9.99E-08	8.01E-08	1.23E-06	3.20E-06	4.72E-07	4.48E-07	3.84E-05	2.19E-06	1.72E-06	4.33E-07	3.22E-05
Ni (mg/kg)	mean	1.85E-02	1.36E-02	1.12E-02	5.58E-02	1.91E-02	1.28E-02	1.19E-02	6.11E-02	1.87E-02	1.23E-02	1.25E-02	5.67E-02	5.15E-03	7.04E-03	5.62E-03	1.51E-02	1.93E-02	1.22E-02	1.30E-02	5.90E-02	1.69E-02	3.37E-02	9.78E-03	5.06E-02
t	variance	7.84E-05	1.18E-06	1.33E-06	1.18E-03	8.07E-05	1.01E-06	9.39E-07	1.37E-03	5.48E-05	9.59E-07	1.02E-06	1.52E-03	3.53E-06	3.03E-07	1.96E-07	7.19E-05	5.71E-05	9.36E-07	1.03E-06	1.06E-03	5.53E-05	1.26E-05	1.04E-06	1.03E-03
Mg (mg/l)	mean	2.08E-02	9.25E-03	7.64E-03	7.59E-02	2.26E-02	8.03E-03	7.65E-03	7.49E-02	2.24E-02	8.73E-03	7.61E-03	8.31E-02	6.11E-03	4.99E-03	3.88E-03	2.07E-02	2.26E-02	7.35E-03	8.01E-03	8.97E-02	2.05E-02	3.38E-02	5.00E-03	7.52E-02
t	variance	1.25E-04	5.83E-07	9.88E-07	1.85E-03	9.38E-05	4.18E-07	3.81E-07	1.86E-03	1.34E-04	4.66E-07	4.60E-07	3.16E-03	5.23E-06	1.75E-07	1.09E-07	8.20E-05	9.74E-05	3.35E-07	3.97E-07	4.35E-03	1.23E-04	1.19E-05	5.40E-07	2.62E-03
K (mg/l)	mean	1.57E-02	1.94E-02	1.66E-02	4.33E-02	1.53E-02	1.85E-02	1.90E-02	4.27E-02	1.52E-02	1.92E-02	1.86E-02	4.05E-02	4.23E-03	8.70E-03	8.36E-03	1.14E-02	1.58E-02	1.94E-02	1.95E-02	4.42E-02	1.52E-02	2.08E-02	1.95E-02	4.06E-02
t	variance	1.72E-05	2.90E-06	8.87E-05	3.94E-04	1.39E-05	7.11E-06	6.94E-06	3.45E-04	1.35E-05	2.40E-06	1.41E-05	4.10E-04	3.49E-07	1.11E-06	1.34E-06	1.14E-05	1.57E-05	2.38E-06	4.64E-06	3.37E-04	1.81E-05	6.31E-06	3.60E-06	3.66E-04
C/N	mean	8.96E-04	4.82E-04	4.55E-04	3.70E-03	9.33E-04	4.60E-04	4.20E-04	3.79E-03	9.39E-04	5.13E-04	4.46E-04	4.04E-03	2.50E-04	3.11E-04	1.83E-04	1.02E-03	9.06E-04	4.02E-04	4.49E-04	3.53E-03	8.20E-04	1.54E-03	3.07E-04	3.35E-03
t	variance	1.97E-07	1.58E-09	1.96E-09	7.30E-06	2.31E-07	1.42E-09	1.13E-09	5.16E-06	1.52E-07	2.10E-09	1.36E-09	5.84E-06	9.43E-09	7.01E-10	2.49E-10	2.25E-07	1.86E-07	9.76E-10	1.49E-09	3.90E-06	1.82E-07	2.13E-08	1.12E-09	3.84E-06
Change in SOC (%)	mean	1.15E+00	2.37E+00	2.22E+00	1.12E+00	1.58E+00	2.36E+00	2.26E+00	1.59E+00	2.29E+00	2.38E+00	2.27E+00	2.50E+00	3.23E-01	1.03E+00	9.73E-01	3.43E-01	1.77E+00	2.37E+00	2.28E+00	1.91E+00	9.01E-01	2.36E+00	2.19E+00	8.95E-01
	variance	8.45E-02	6.28E-02	7.40E-02	2.89E-01	3.37E-01	5.91E-02	7.26E-02	8.55E-01	1.11E+00	5.99E-02	7.07E-02	2.11E+00	3.47E-03	1.18E-02	1.22E-02	7.76E-03	2.58E-01	5.83E-02	7.11E-02	9.32E-01	1.28E-01	5.84E-02	7.83E-02	2.21E-01
Distance (km)		2.41E+03	2.21E+03	2.67E+03	1.28E+03																				

Appendix E

Land cover classes within which the sample variance is less than critical variance for SOC change



England

	Bog				dwarf shrub heath				Broad-leaved / mixed woodlan				Coniferous woodland				Improved grassland				Semi-natural grass				Arable and horticulture				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
1000	No	No	No		No	No	No		No	No	No		No	No	No		Yes	No	No		No	No	No		Yes	No	No		No	No	No	
2000	Yes	Yes	Yes		No	No	No		No	No	No		No	No	No		Yes	No	No		Yes	No	Yes		Yes	No	No		Yes	No	No	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	Yes	Yes

Scotland No Montane Habitats with SOC change

	Bog				dwarf shrub heath				Broad-leaved / mixed woodlan				Coniferous woodland				Improved grassland				Semi-natural grass				Arable and horticulture				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
1000	Yes	No	No		Yes	Yes	Yes		No	No	No		Yes	No	No		Yes	No	No		Yes	No	No		Yes	No	No		No	No	No	
2000	Yes	No	No		Yes	Yes	Yes		No	No	No		Yes	Yes	Yes		Yes	No	No		Yes	Yes	Yes		Yes	No	No		No	No	No	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	Yes	No	No	Yes

A model for change could not be obtained in Class "Montane Habitats"

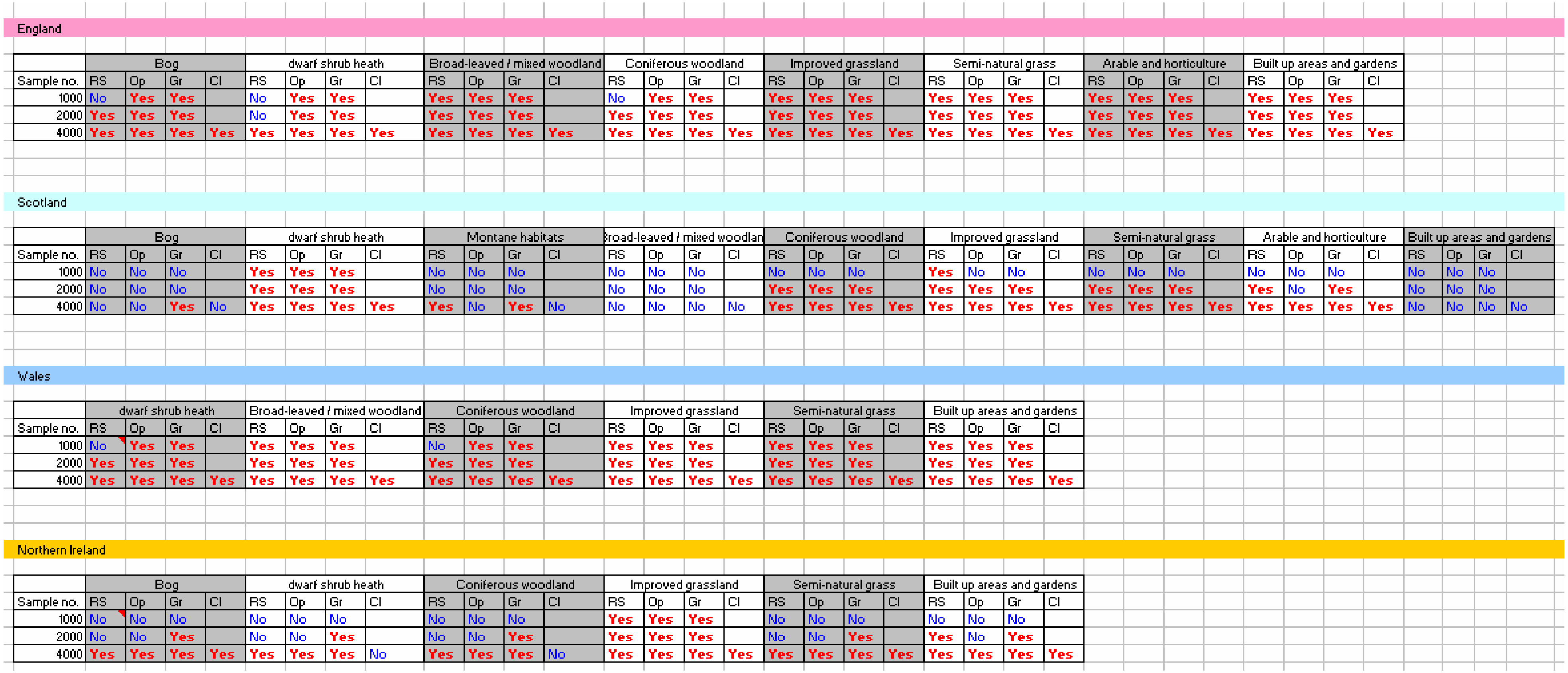
Wales

	dwarf shrub heath				Broad-leaved / mixed woodlan				Coniferous woodland				Improved grassland				Semi-natural grass				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
1000	No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		No	No	No	
2000	No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		No	No	No	
4000	Yes	Yes	No	Yes	No	No	No	No	No	No	No	No	Yes	No	No	Yes	No	No	No	No	No	No	No	No

Northern Ireland

	Bog				dwarf shrub heath				Coniferous woodland				Improved grassland				Semi-natural grass				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
1000	No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		No	No	No	
2000	Yes	Yes	No		Yes	Yes	Yes		No	Yes	No		No	No	No		No	No	No		No	No	No	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	No	No	No	No	No

Land cover classes able to estimate mean organic carbon levels within 5% SOC



England

	Bog				dwarf shrub heath				Broad-leaved / mixed woodland				Coniferous woodland				Improved grassland				Semi-natural grass				Arable and horticulture				Built up areas and gardens			
Sample no.	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI
1000	No	Yes	Yes		No	Yes	Yes		Yes	Yes	Yes		No	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
2000	Yes	Yes	Yes		No	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Scotland

	Bog				dwarf shrub heath				Montane habitats				road-leaved / mixed woodlan				Coniferous woodland				Improved grassland				Semi-natural grass				Arable and horticulture				Built up areas and gardens			
Sample no.	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI
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2000	No	No	No		Yes	Yes	Yes		No	No	No		No	No	No		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	No	Yes		No	No	No	
4000	No	No	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No

Wales

	dwarf shrub heath				Broad-leaved / mixed woodland				Coniferous woodland				Improved grassland				Semi-natural grass				Built up areas and gardens			
Sample no.	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI
1000	No	Yes	Yes		Yes	Yes	Yes		No	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
2000	Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Northern Ireland

	Bog				dwarf shrub heath				Coniferous woodland				Improved grassland				Semi-natural grass				Built up areas and gardens			
Sample no.	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI
1000	No	No	No		No	No	No		No	No	No		Yes	Yes	Yes		No	No	No		No	No	No	
2000	No	No	Yes		No	No	Yes		No	No	Yes		Yes	Yes	Yes		No	No	Yes		Yes	No	Yes	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Land cover classes able to estimate mean pH to within +/- 0.5 pH unit

England

	Bog				dwarf shrub heath				Broad-leaved / mixed woodland				Coniferous woodland				Improved grassland				Semi-natural grass				Arable and horticulture				Built up areas and gardens			
Sample no.	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI
1000	No	No	No		No	No	No		Yes	Yes	Yes		No	No	No		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
2000	Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Scotland

	Bog				dwarf shrub heath				Montane habitats				Broad-leaved / mixed woodlan				Coniferous woodland				Improved grassland				Semi-natural grass				Arable and horticulture				Built up areas and gardens			
Sample no.	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI
1000	Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
2000	Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Wales

	dwarf shrub heath				Broad-leaved / mixed woodland				Coniferous woodland				Improved grassland				Semi-natural grass				Built up areas and gardens			
Sample no.	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI
1000	No	No	No		No	No	No		No	No	No		Yes	Yes	Yes		Yes	Yes	Yes		No	No	No	
2000	Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Northern Ireland

	Bog				dwarf shrub heath				Coniferous woodland				Improved grassland				Semi-natural grass				Built up areas and gardens			
Sample no.	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI	RS	Op	Gr	CI
1000	Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
2000	Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Land cover classes which meet the minimum detectable change criteria of 5mg/kg for Zn

England

	Bog				dwarf shrub heath				Broad-leaved / mixed woodland				Coniferous woodland				Improved grassland				Semi-natural grass				Arable and horticulture				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
1000	No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		No	No	No	
2000	No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		Yes	No	No		No	No	No	
4000	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No	Yes	No	No	No	No	No	No	No

Scotland

	Bog				dwarf shrub heath				Montane habitats				Broad-leaved / mixed woodland				Coniferous woodland				Improved grassland				Semi-natural grass				Arable and horticulture				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
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2000	No	No	No		Yes	Yes	Yes		No	No	No		No	No	No		Yes	Yes	Yes		No	No	No		No	No	No		No	No	No		No	No	No	
4000	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	No	No	No	Yes	No	Yes	No	No	No	No	No	No	No	No	No

Wales

	dwarf shrub heath				Broad-leaved / mixed woodland				Coniferous woodland				Improved grassland				Semi-natural grass				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
1000	No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		No	No	No	
2000	No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		No	No	No	
4000	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No

Northern Ireland

	Bog				dwarf shrub heath				Coniferous woodland				Improved grassland				Semi-natural grass				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
1000	No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		No	No	No	
2000	No	No	No		No	No	No		No	No	No		No	No	No		No	No	No		No	No	No	
4000	Yes	No	No	No	No	No	No	No	Yes	Yes	Yes	No	No	No	No	No	No	No	No	No	No	No	No	No

Land cover classes which meet the minimum detectable change criteria of 5mg/kg for Cu

England

	Bog				dwarf shrub heath				Broad-leaved / mixed woodland				Coniferous woodland				Improved grassland				Semi-natural grass				Arable and horticulture				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
1000	No	No	No		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
2000	Yes	No	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes	
4000	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Scotland

	Bog				dwarf shrub heath				Montane habitats				Broad-leaved / mixed woodland				Coniferous woodland				Improved grassland				Semi-natural grass				Arable and horticulture				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
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2000	Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		No	No	No	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No

Wales

	dwarf shrub heath				Broad-leaved / mixed woodland				Coniferous woodland				Improved grassland				Semi-natural grass				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
1000	Yes	Yes	Yes		No	No	No		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		No	No	No	
2000	Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		No	No	No	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No

Northern Ireland

	Bog				dwarf shrub heath				Coniferous woodland				Improved grassland				Semi-natural grass				Built up areas and gardens			
Sample no.	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl	RS	Op	Gr	Cl
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2000	Yes	Yes	Yes		No	Yes	Yes		Yes	Yes	Yes		Yes	Yes	Yes		No	Yes	Yes		No	No	No	
4000	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No	Yes	No

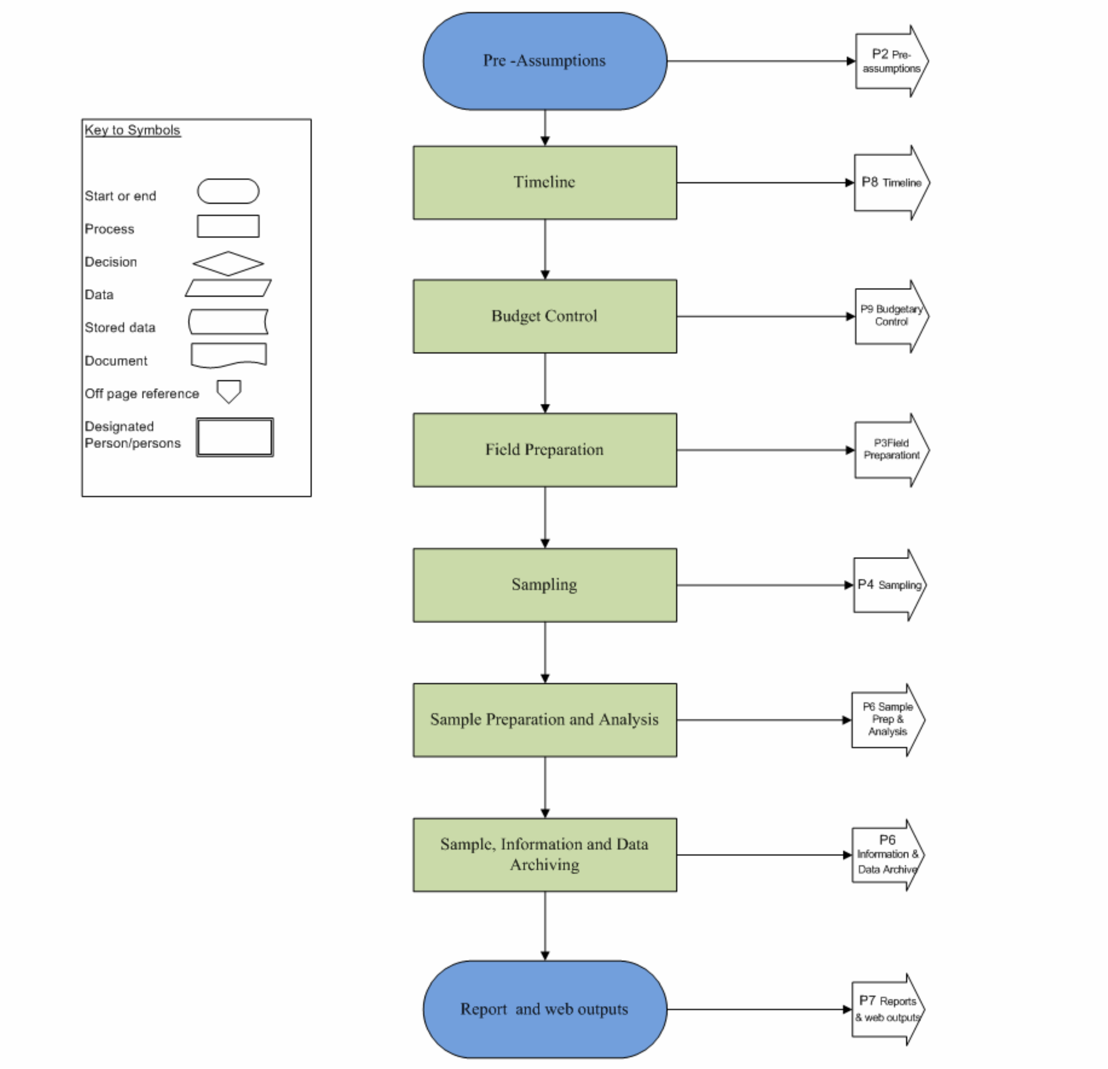
Appendix F

Process Map

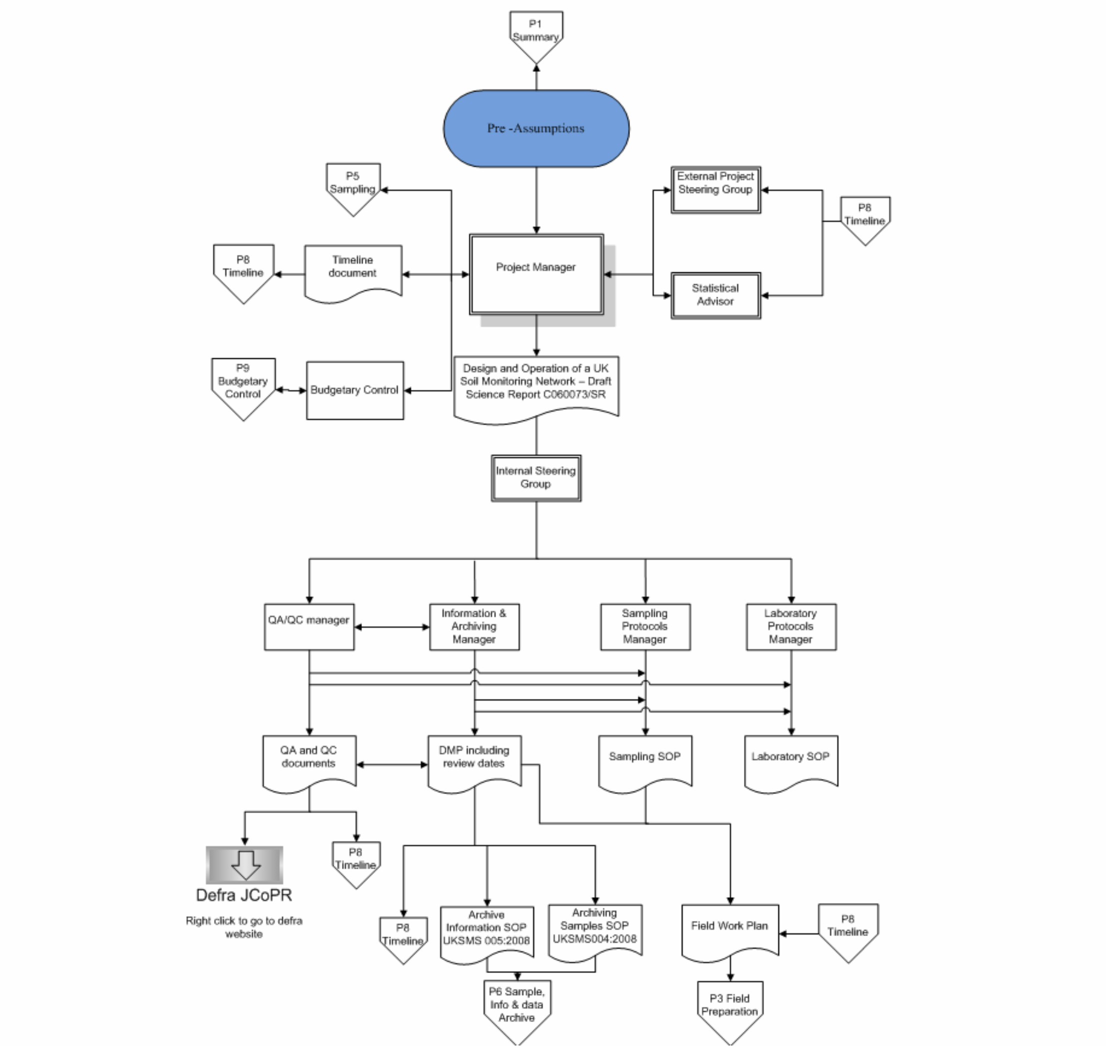
Including:

- Map P1 Summary of the process map for soil monitoring
- Map P2 Pre-Assumptions
- Map P3 Field Preparation
- Map P4 Sampling
- Map P5 Sample Preparation and analysis
- Map P6 Sample, Information & Data Archiving
- Map P7 Report and Web outputs
- Map P8 Timeline
- Map P9 Budget Control

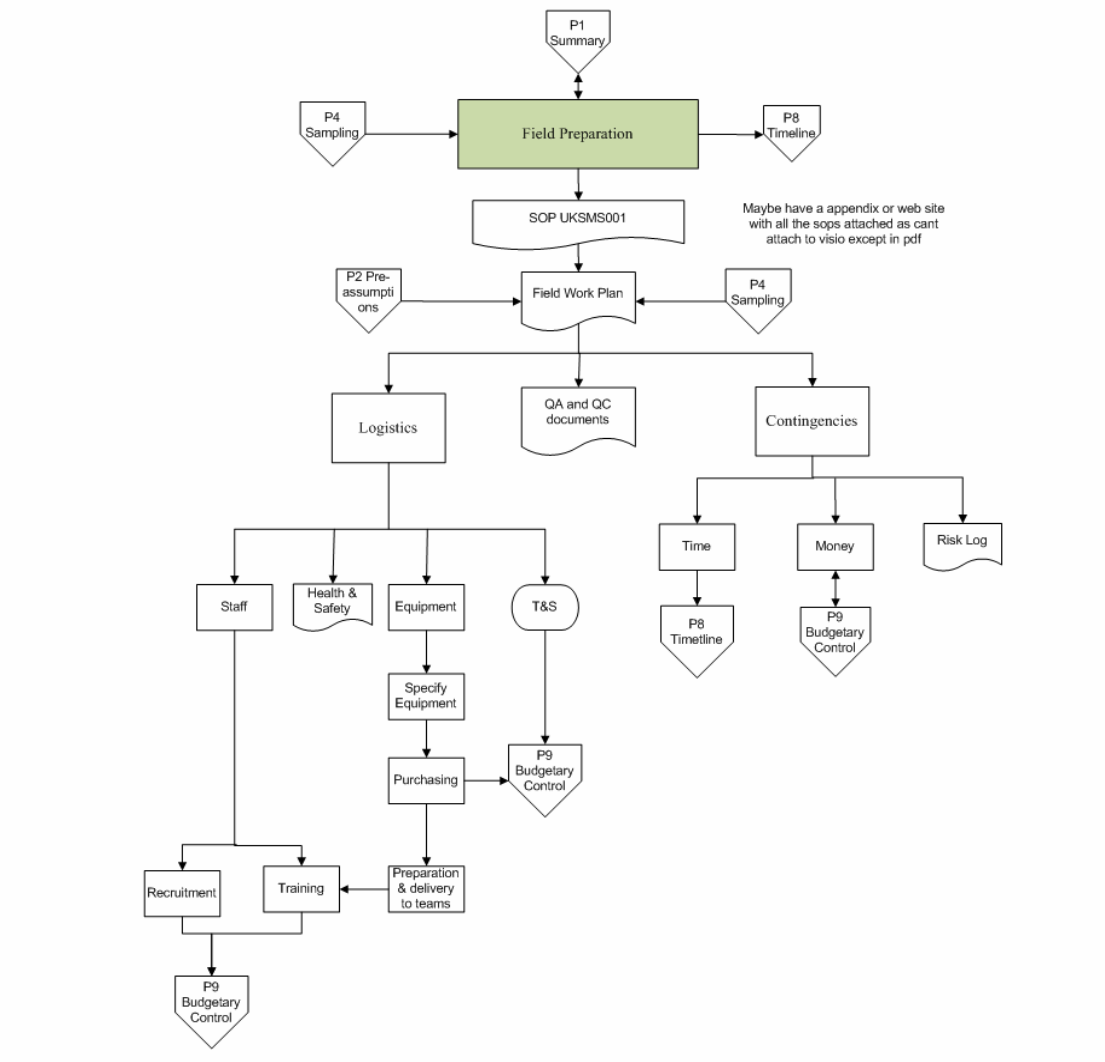
Map P1 Summary of the process map for soil monitoring



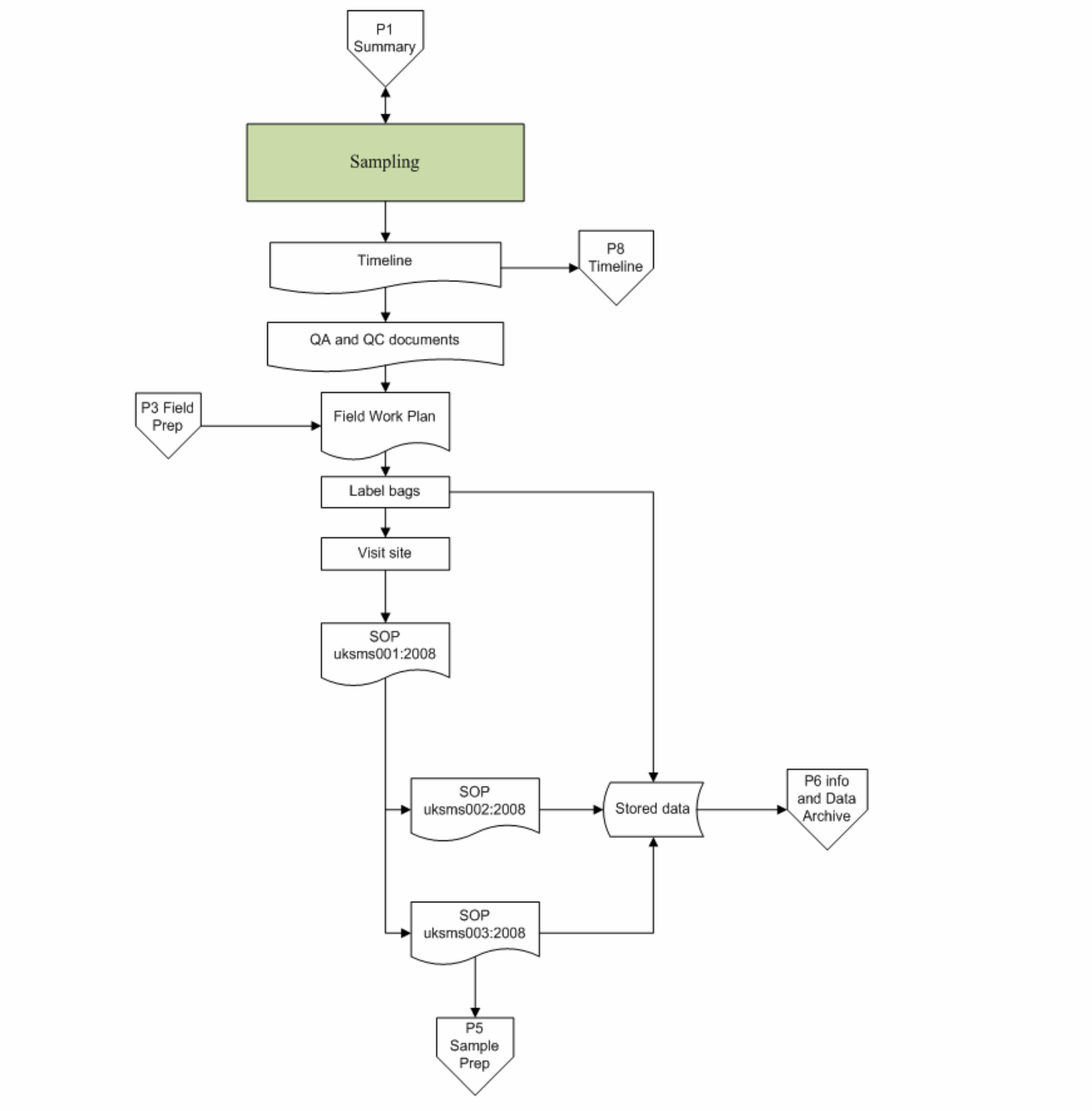
Map P2 Pre-Assumptions



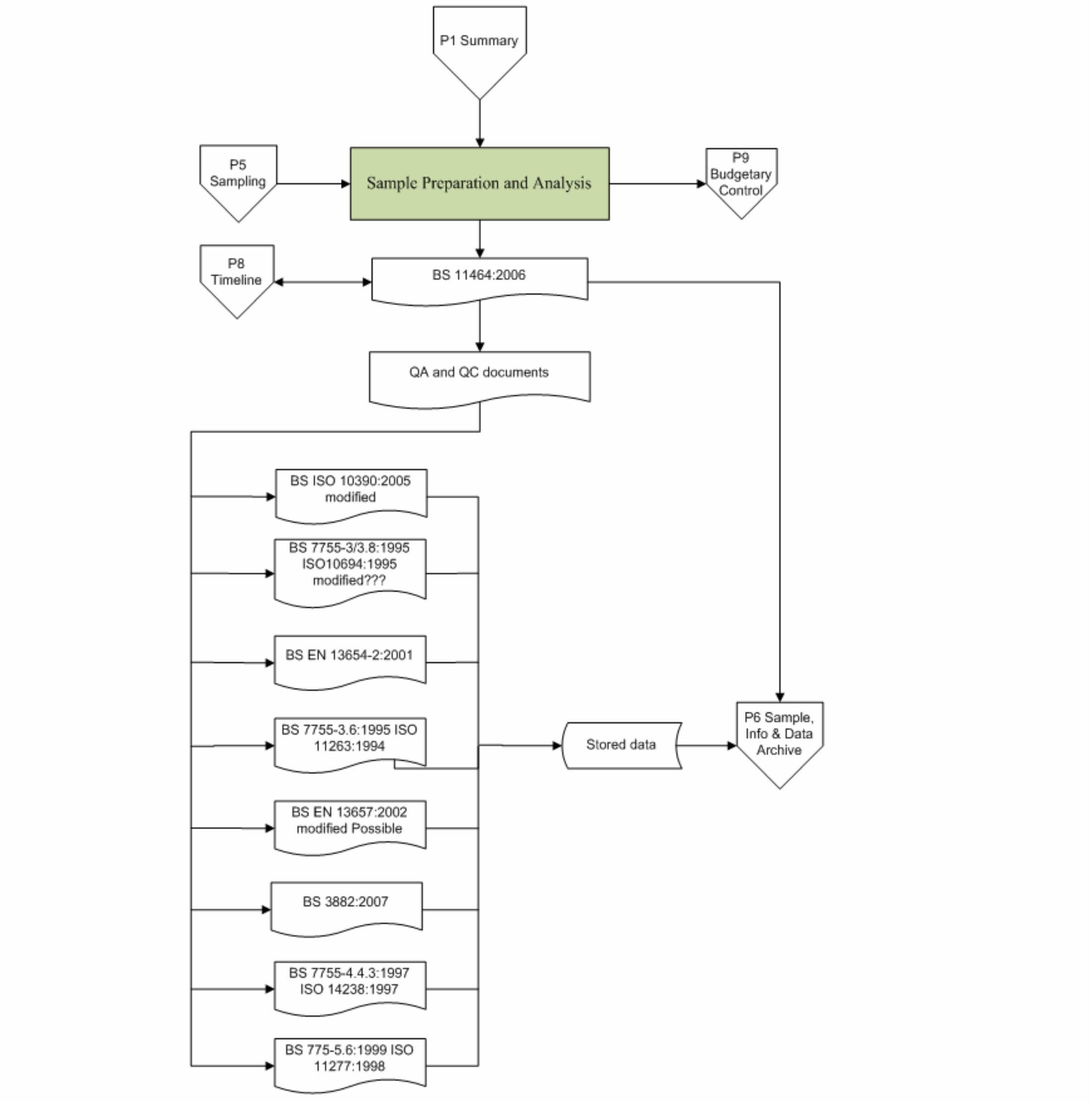
Map P3 Field Preparation



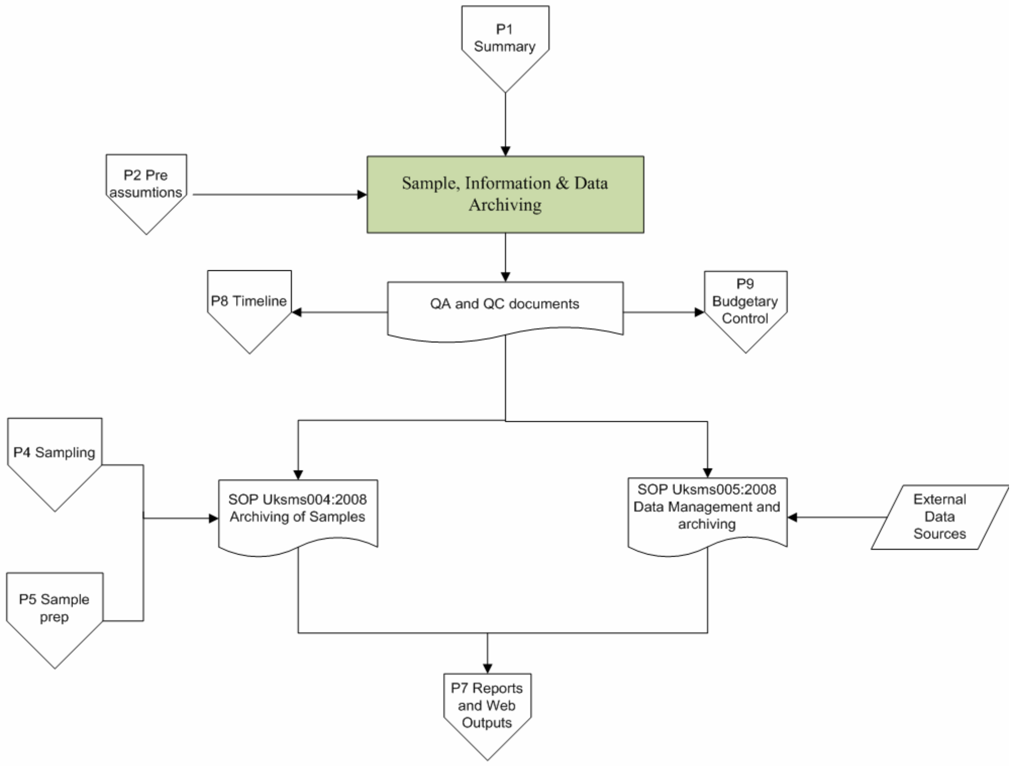
Map P4 Sampling



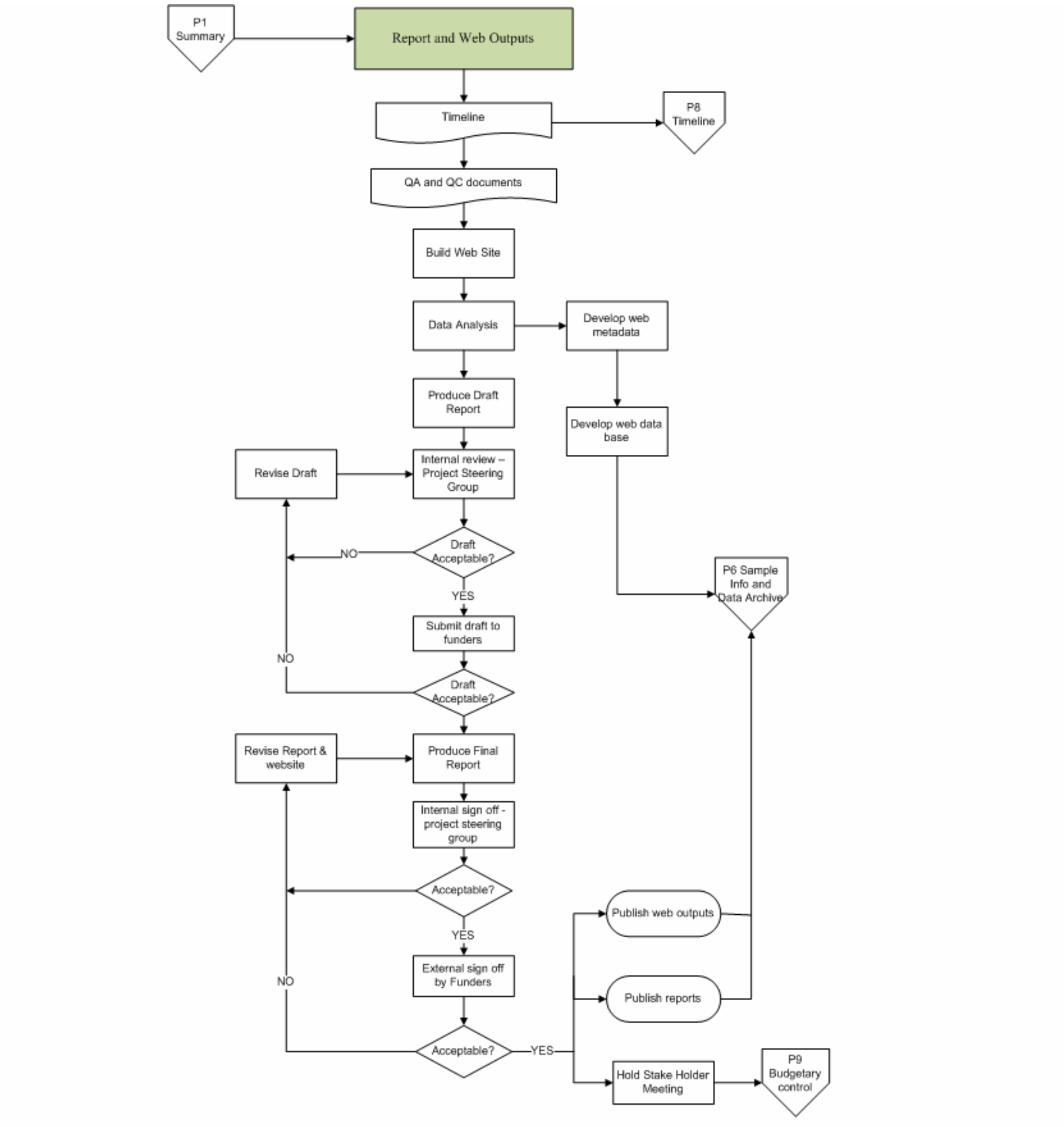
Map P5 Sample Preparation and analysis



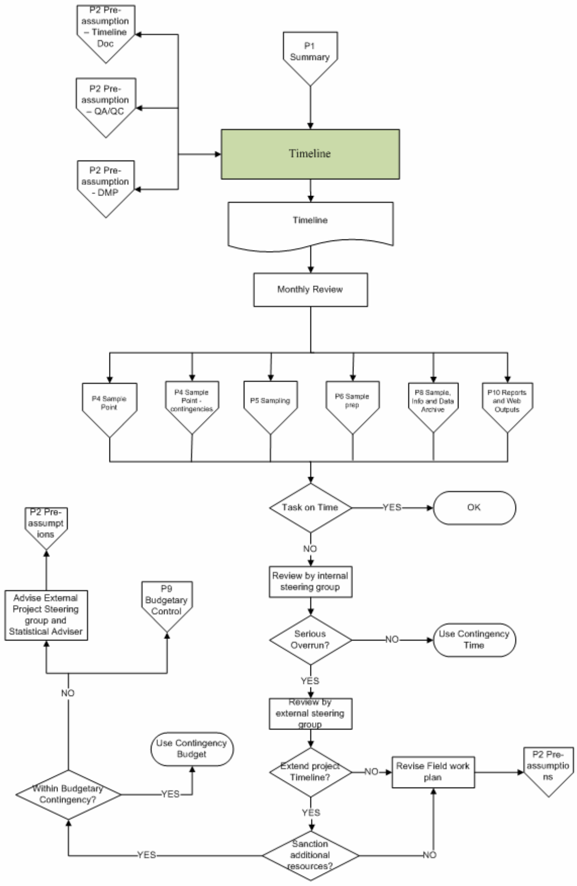
Map P6 Sample, Information & Data Archiving

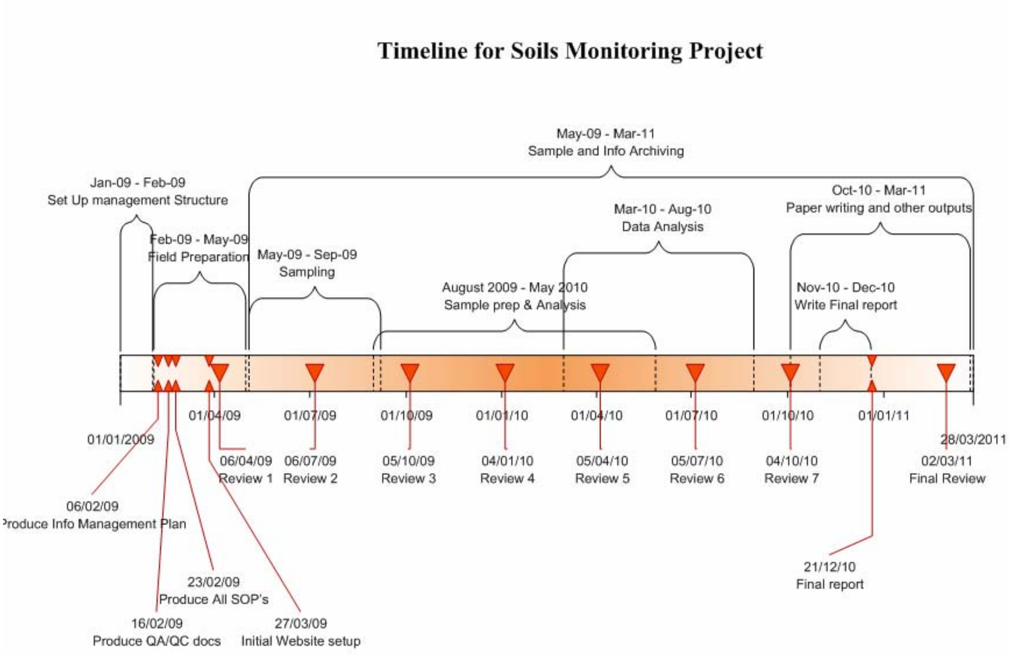


Map P7 Report and Web outputs

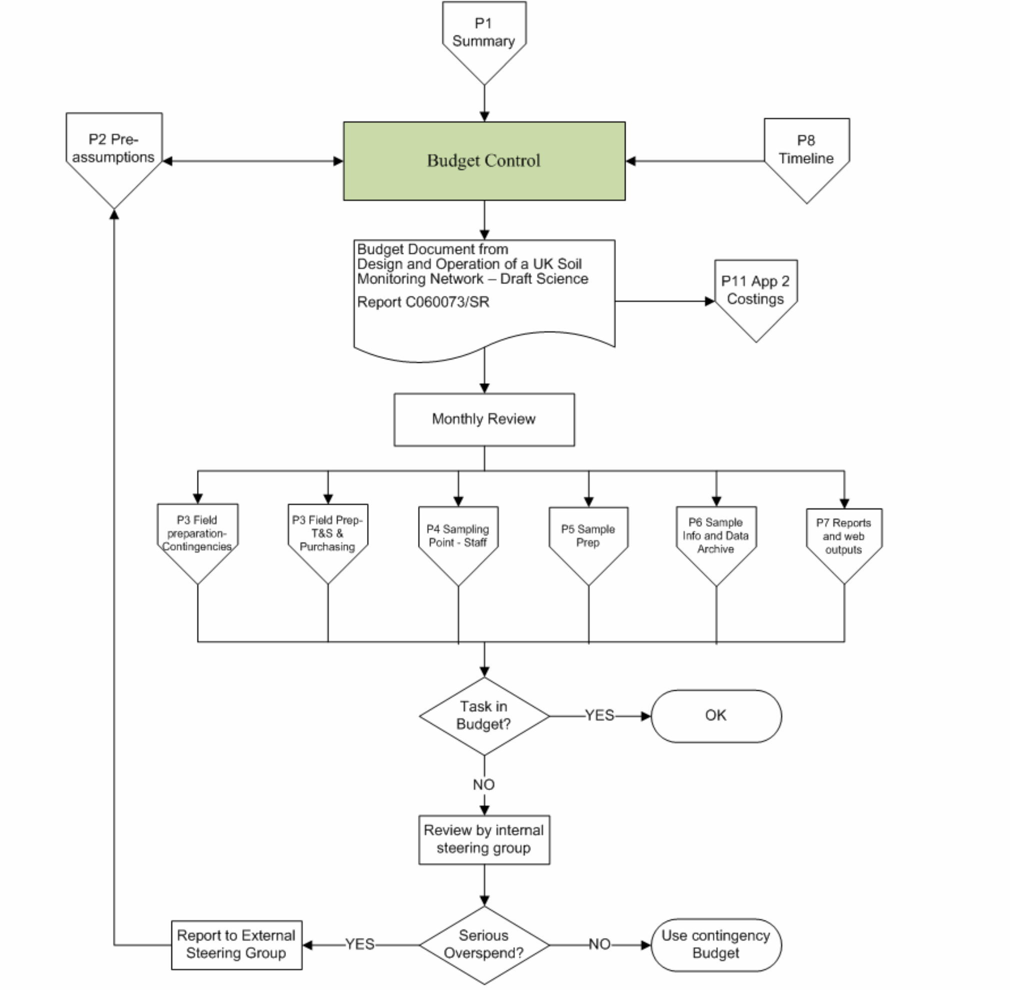


Map P8 Timeline

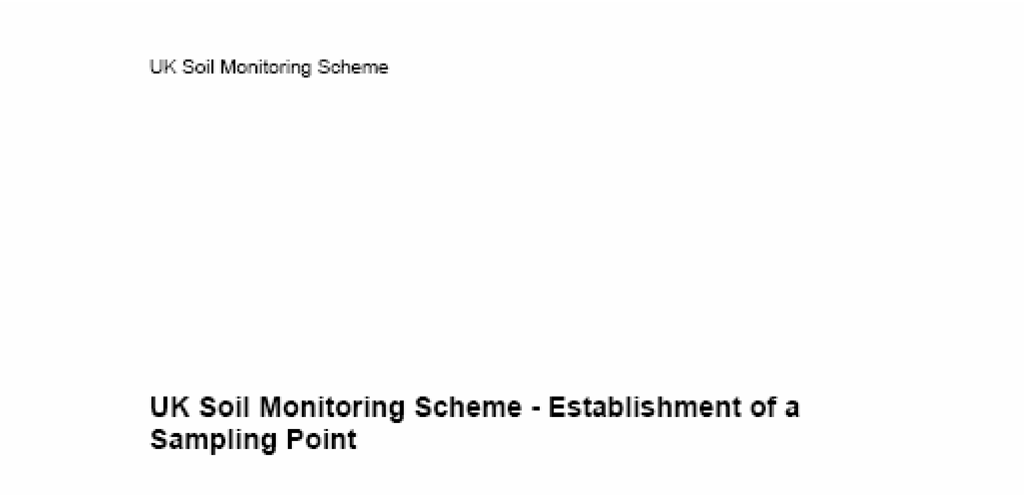




Map P9 Budget

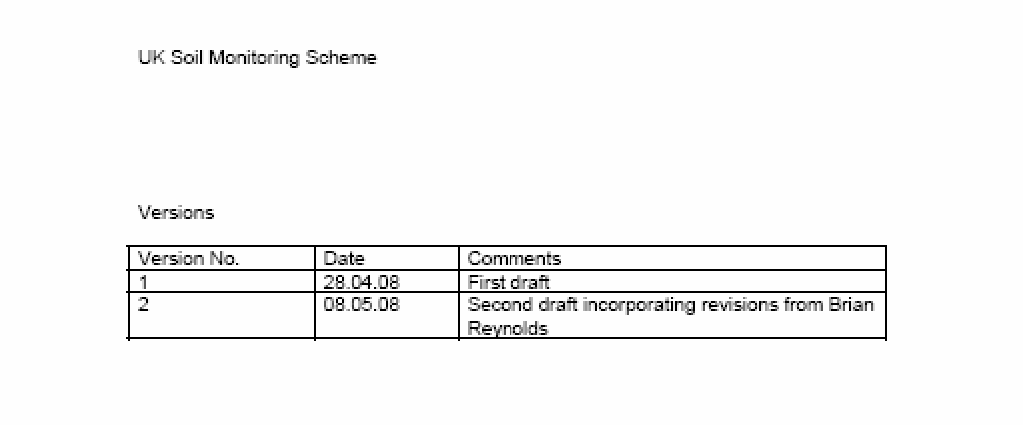


Appendix G



UK Soil Monitoring Scheme

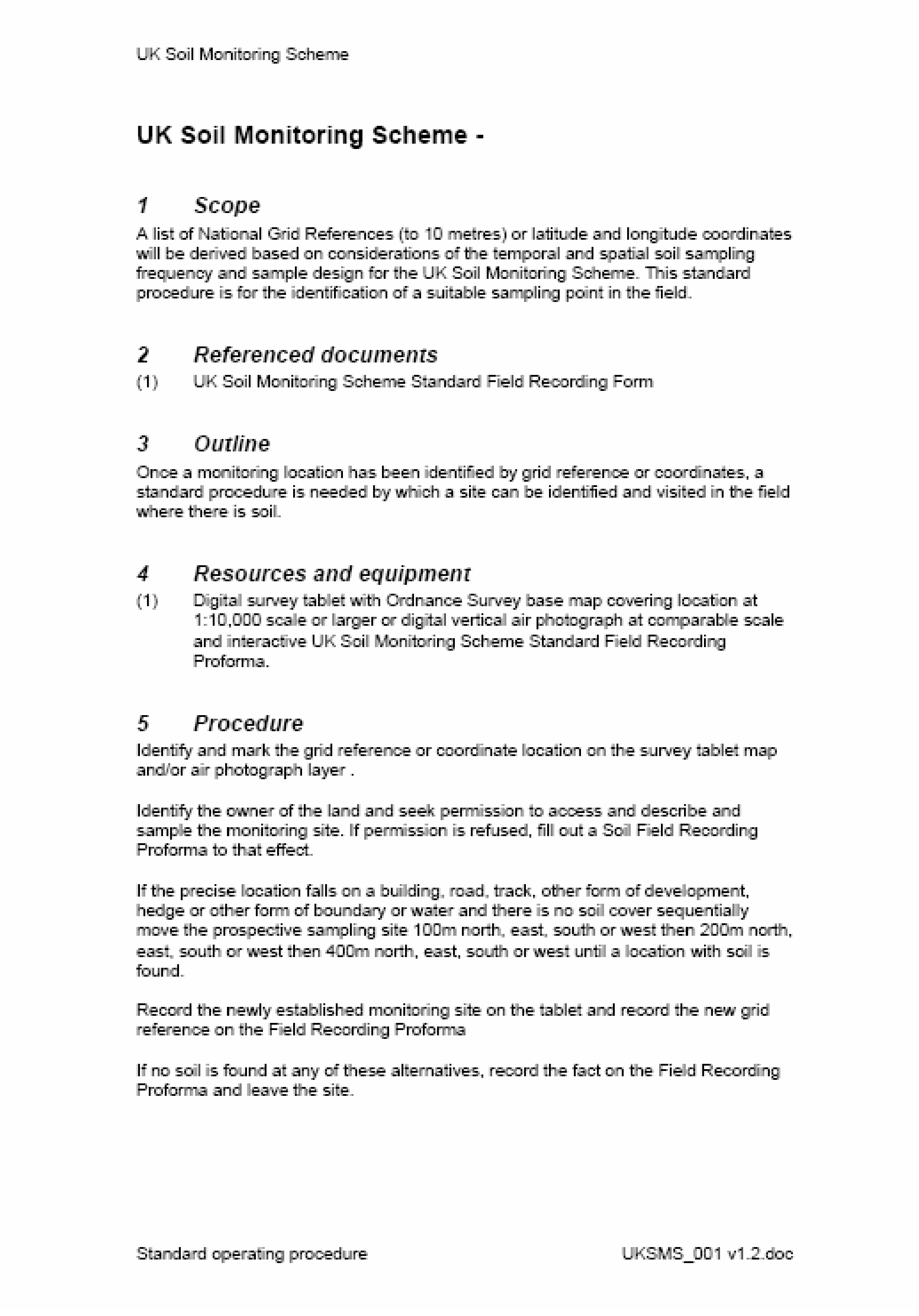
UK Soil Monitoring Scheme - Establishment of a Sampling Point



UK Soil Monitoring Scheme

Versions

Version No.	Date	Comments
1	28.04.08	First draft
2	08.05.08	Second draft incorporating revisions from Brian Reynolds



UK Soil Monitoring Scheme

UK Soil Monitoring Scheme -

1 *Scope*

A list of National Grid References (to 10 metres) or latitude and longitude coordinates will be derived based on considerations of the temporal and spatial soil sampling frequency and sample design for the UK Soil Monitoring Scheme. This standard procedure is for the identification of a suitable sampling point in the field.

2 *Referenced documents*

(1) UK Soil Monitoring Scheme Standard Field Recording Form

3 *Outline*

Once a monitoring location has been identified by grid reference or coordinates, a standard procedure is needed by which a site can be identified and visited in the field where there is soil.

4 *Resources and equipment*

(1) Digital survey tablet with Ordnance Survey base map covering location at 1:10,000 scale or larger or digital vertical air photograph at comparable scale and interactive UK Soil Monitoring Scheme Standard Field Recording Proforma.

5 *Procedure*

Identify and mark the grid reference or coordinate location on the survey tablet map and/or air photograph layer .

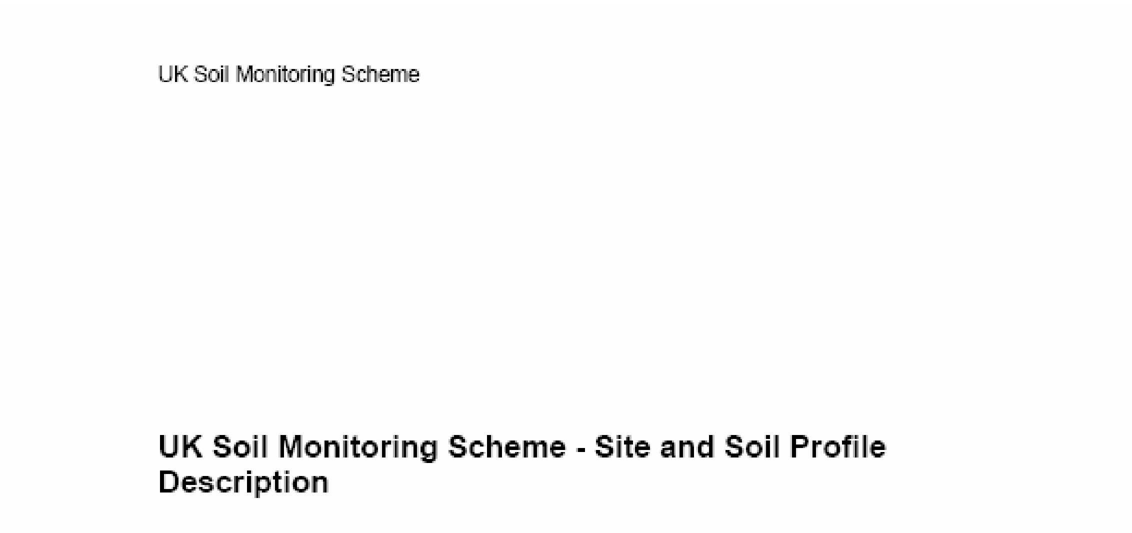
Identify the owner of the land and seek permission to access and describe and sample the monitoring site. If permission is refused, fill out a Soil Field Recording Proforma to that effect.

If the precise location falls on a building, road, track, other form of development, hedge or other form of boundary or water and there is no soil cover sequentially move the prospective sampling site 100m north, east, south or west then 200m north, east, south or west then 400m north, east, south or west until a location with soil is found.

Record the newly established monitoring site on the tablet and record the new grid reference on the Field Recording Proforma

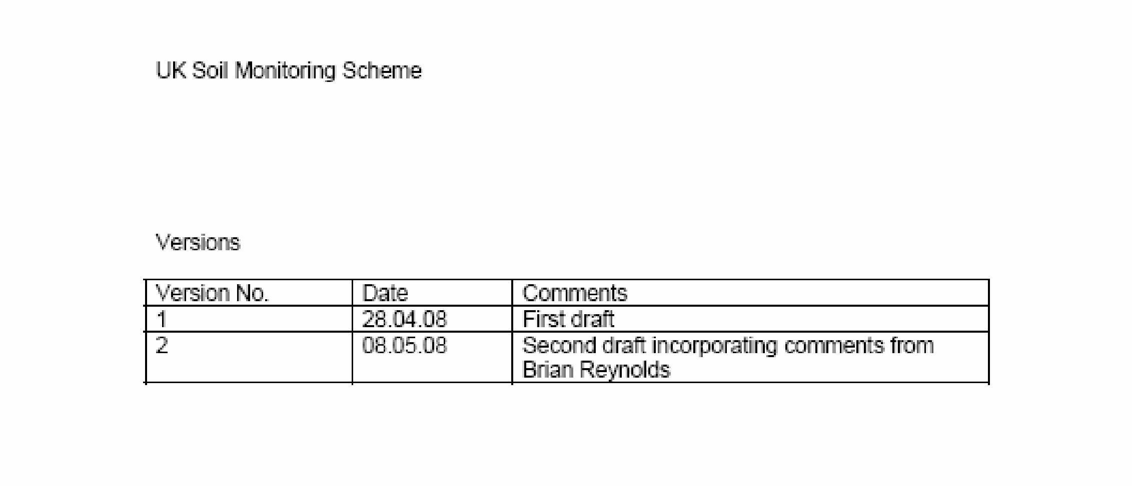
If no soil is found at any of these alternatives, record the fact on the Field Recording Proforma and leave the site.

Standard operating procedure UKSMS_001 v1.2.doc



UK Soil Monitoring Scheme

UK Soil Monitoring Scheme - Site and Soil Profile Description



UK Soil Monitoring Scheme

Versions

Version No.	Date	Comments
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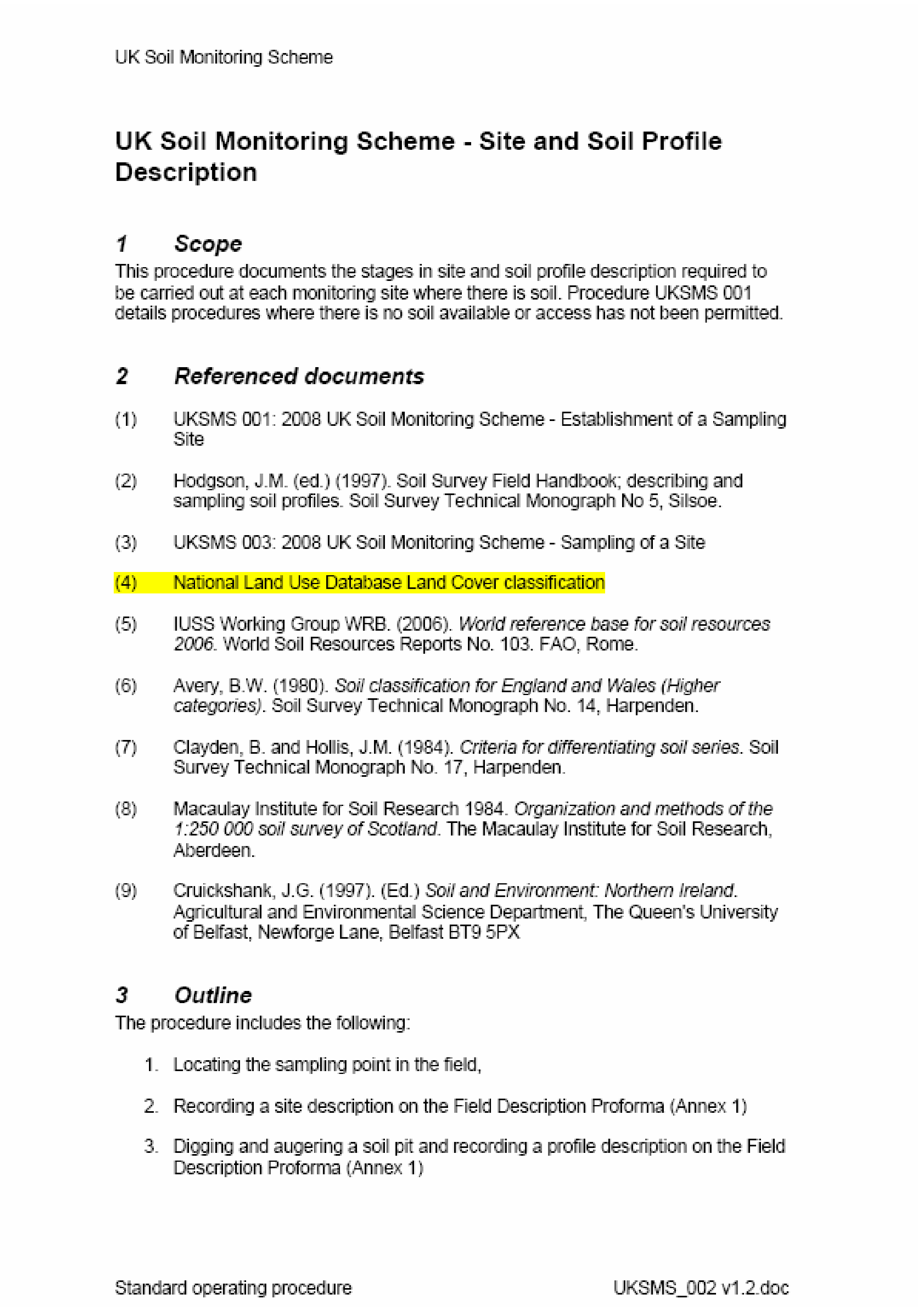
2	08.05.08	Second draft incorporating comments from Brian Reynolds



UK Soil Monitoring Scheme - Site and Soil Profile Description

1 *Scope*

This procedure documents the stages in site and soil profile description required to be carried out at each monitoring site where there is soil. Procedure UKSMS 001 details procedures where there is no soil available or access has not been permitted.

2 *Referenced documents*

(1) UKSMS 001: 2008 UK Soil Monitoring Scheme - Establishment of a Sampling Site

(2) Hodgson, J.M. (ed.) (1997). Soil Survey Field Handbook; describing and sampling soil profiles. Soil Survey Technical Monograph No 5, Silsoe.

(3) UKSMS 003: 2008 UK Soil Monitoring Scheme - Sampling of a Site

(4) National Land Use Database Land Cover classification

(5) IUSS Working Group WRB. (2006). *World reference base for soil resources 2006*. World Soil Resources Reports No. 103. FAO, Rome.

(6) Avery, B.W. (1980). *Soil classification for England and Wales (Higher categories)*. Soil Survey Technical Monograph No. 14, Harpenden.

(7) Clayden, B. and Hollis, J.M. (1984). *Criteria for differentiating soil series*. Soil Survey Technical Monograph No. 17, Harpenden.

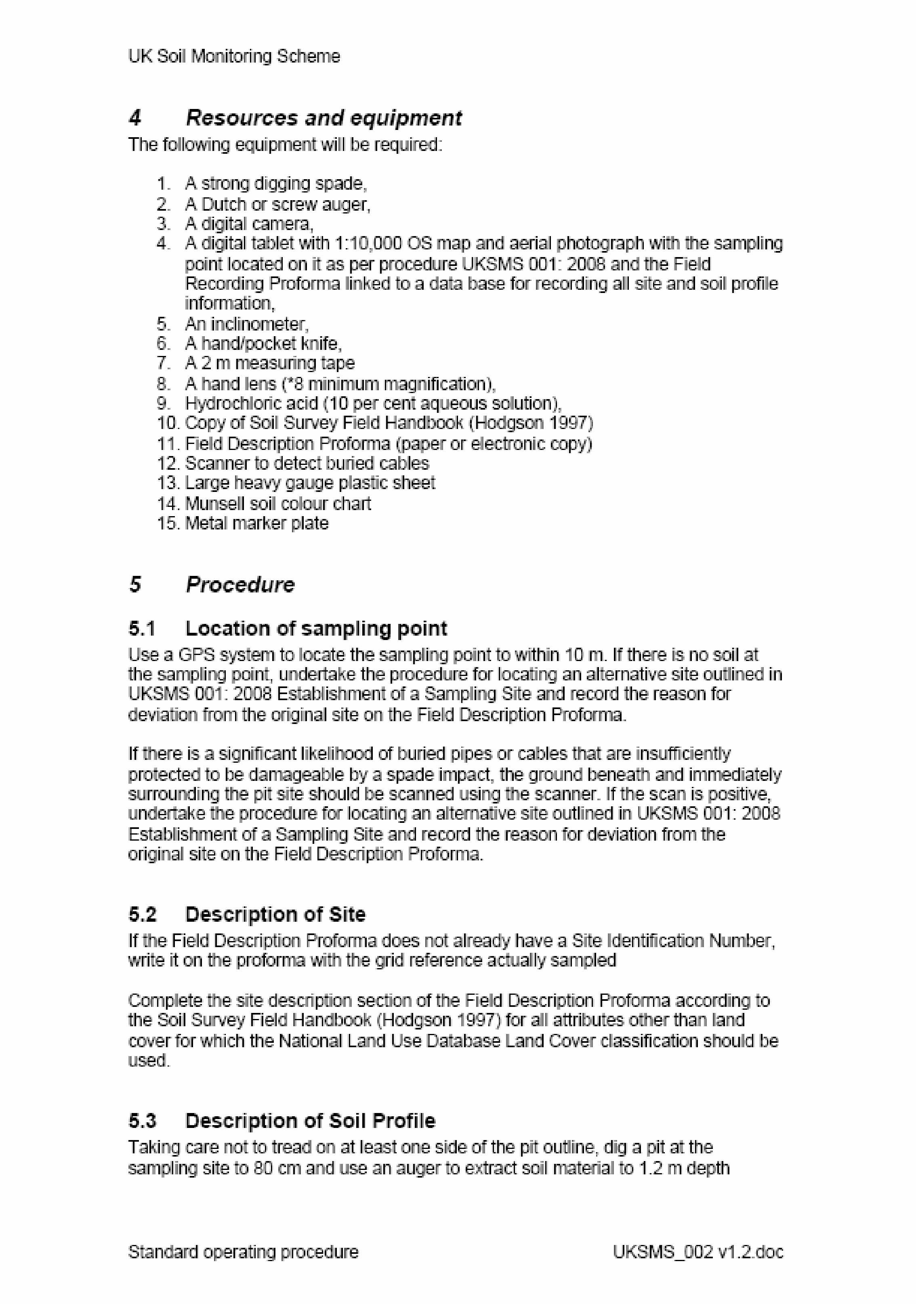
(8) Macaulay Institute for Soil Research 1984. *Organization and methods of the 1:250 000 soil survey of Scotland*. The Macaulay Institute for Soil Research, Aberdeen.

(9) Cruickshank, J.G. (1997). (Ed.) *Soil and Environment: Northern Ireland*. Agricultural and Environmental Science Department, The Queen's University of Belfast, Newforge Lane, Belfast BT9 5PX

3 *Outline*

The procedure includes the following:

1. Locating the sampling point in the field,
2. Recording a site description on the Field Description Proforma (Annex 1)
3. Digging and augering a soil pit and recording a profile description on the Field Description Proforma (Annex 1)



4 Resources and equipment

The following equipment will be required:

1. A strong digging spade,
2. A Dutch or screw auger,
3. A digital camera,
4. A digital tablet with 1:10,000 OS map and aerial photograph with the sampling point located on it as per procedure UKSMS 001: 2008 and the Field Recording Proforma linked to a data base for recording all site and soil profile information,
5. An inclinometer,
6. A hand/pocket knife,
7. A 2 m measuring tape
8. A hand lens (*8 minimum magnification),
9. Hydrochloric acid (10 per cent aqueous solution),
10. Copy of Soil Survey Field Handbook (Hodgson 1997)
11. Field Description Proforma (paper or electronic copy)
12. Scanner to detect buried cables
13. Large heavy gauge plastic sheet
14. Munsell soil colour chart
15. Metal marker plate

5 Procedure

5.1 Location of sampling point

Use a GPS system to locate the sampling point to within 10 m. If there is no soil at the sampling point, undertake the procedure for locating an alternative site outlined in UKSMS 001: 2008 Establishment of a Sampling Site and record the reason for deviation from the original site on the Field Description Proforma.

If there is a significant likelihood of buried pipes or cables that are insufficiently protected to be damageable by a spade impact, the ground beneath and immediately surrounding the pit site should be scanned using the scanner. If the scan is positive, undertake the procedure for locating an alternative site outlined in UKSMS 001: 2008 Establishment of a Sampling Site and record the reason for deviation from the original site on the Field Description Proforma.

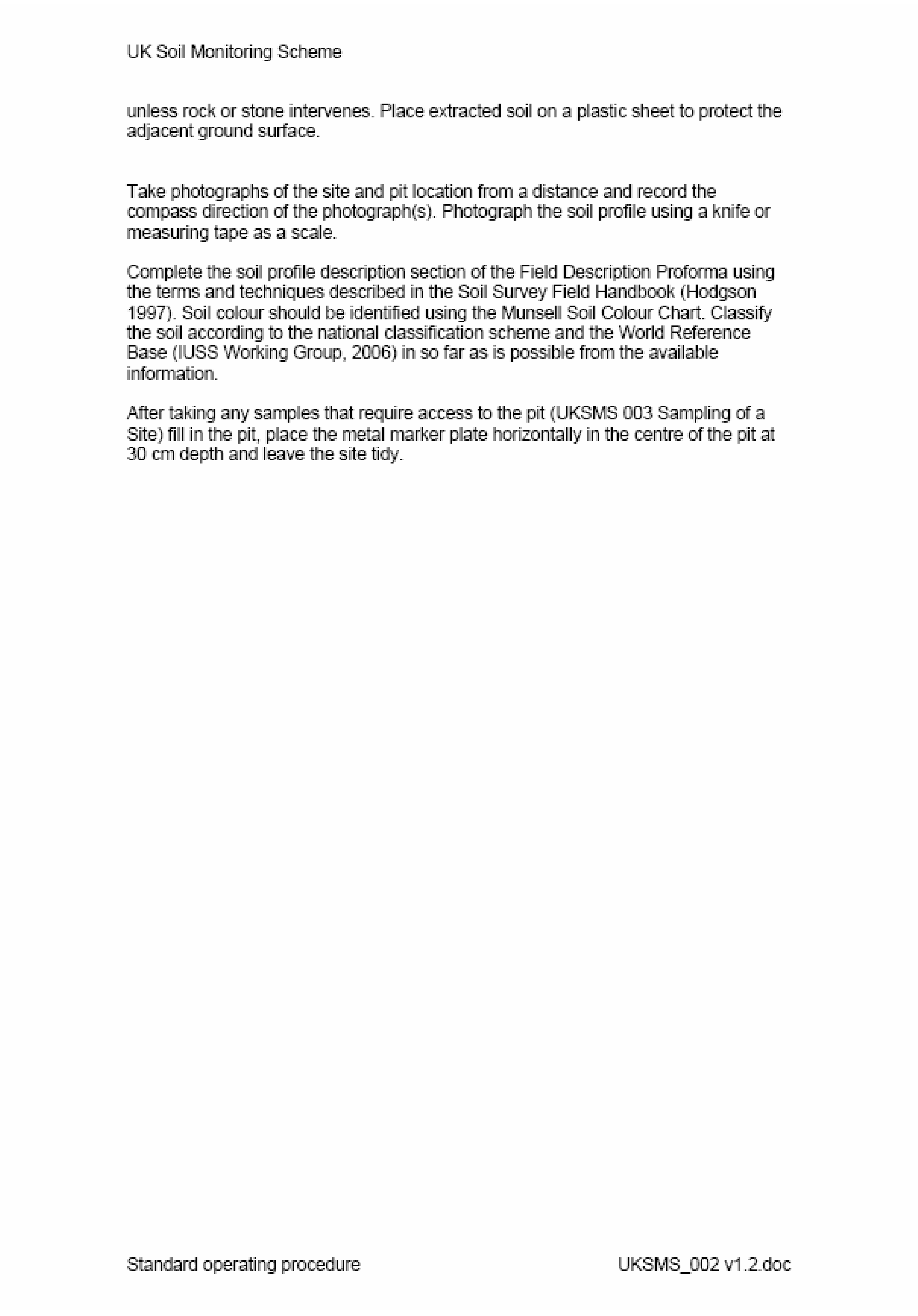
5.2 Description of Site

If the Field Description Proforma does not already have a Site Identification Number, write it on the proforma with the grid reference actually sampled

Complete the site description section of the Field Description Proforma according to the Soil Survey Field Handbook (Hodgson 1997) for all attributes other than land cover for which the National Land Use Database Land Cover classification should be used.

5.3 Description of Soil Profile

Taking care not to tread on at least one side of the pit outline, dig a pit at the sampling site to 80 cm and use an auger to extract soil material to 1.2 m depth

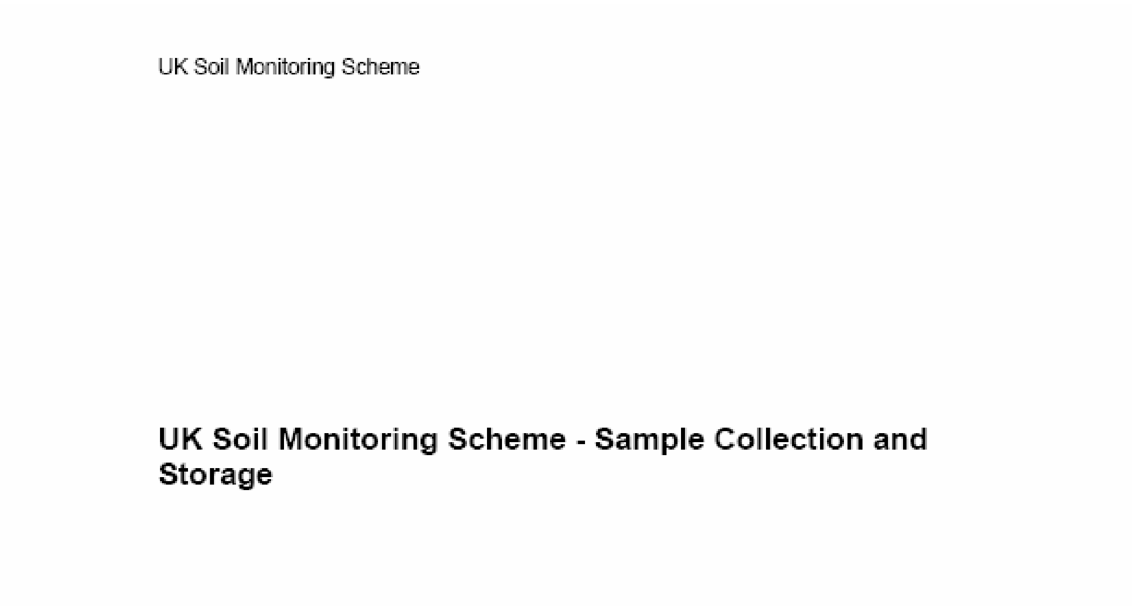


unless rock or stone intervenes. Place extracted soil on a plastic sheet to protect the adjacent ground surface.

Take photographs of the site and pit location from a distance and record the compass direction of the photograph(s). Photograph the soil profile using a knife or measuring tape as a scale.

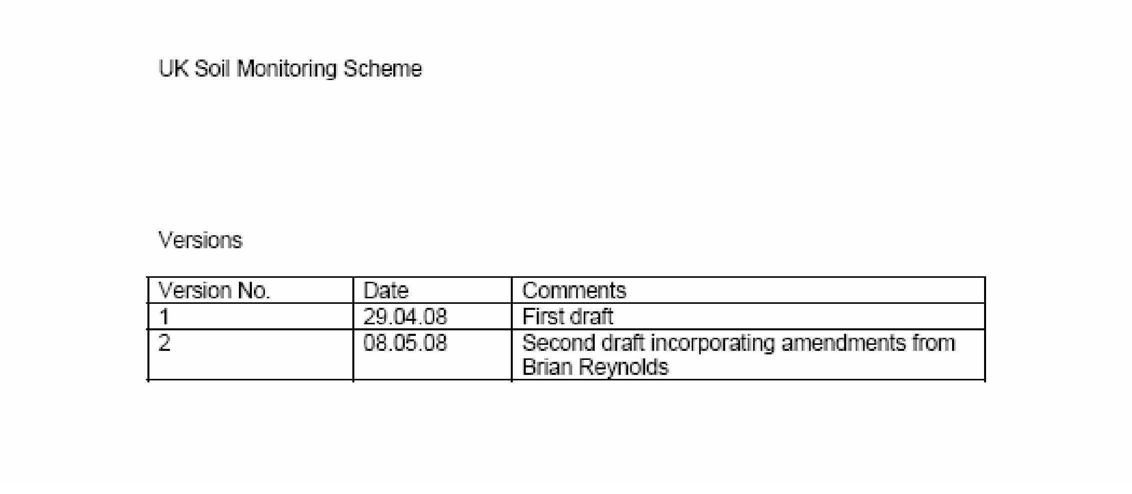
Complete the soil profile description section of the Field Description Proforma using the terms and techniques described in the Soil Survey Field Handbook (Hodgson 1997). Soil colour should be identified using the Munsell Soil Colour Chart. Classify the soil according to the national classification scheme and the World Reference Base (IUSS Working Group, 2006) in so far as is possible from the available information.

After taking any samples that require access to the pit (UKSMS 003 Sampling of a Site) fill in the pit, place the metal marker plate horizontally in the centre of the pit at 30 cm depth and leave the site tidy.



UK Soil Monitoring Scheme

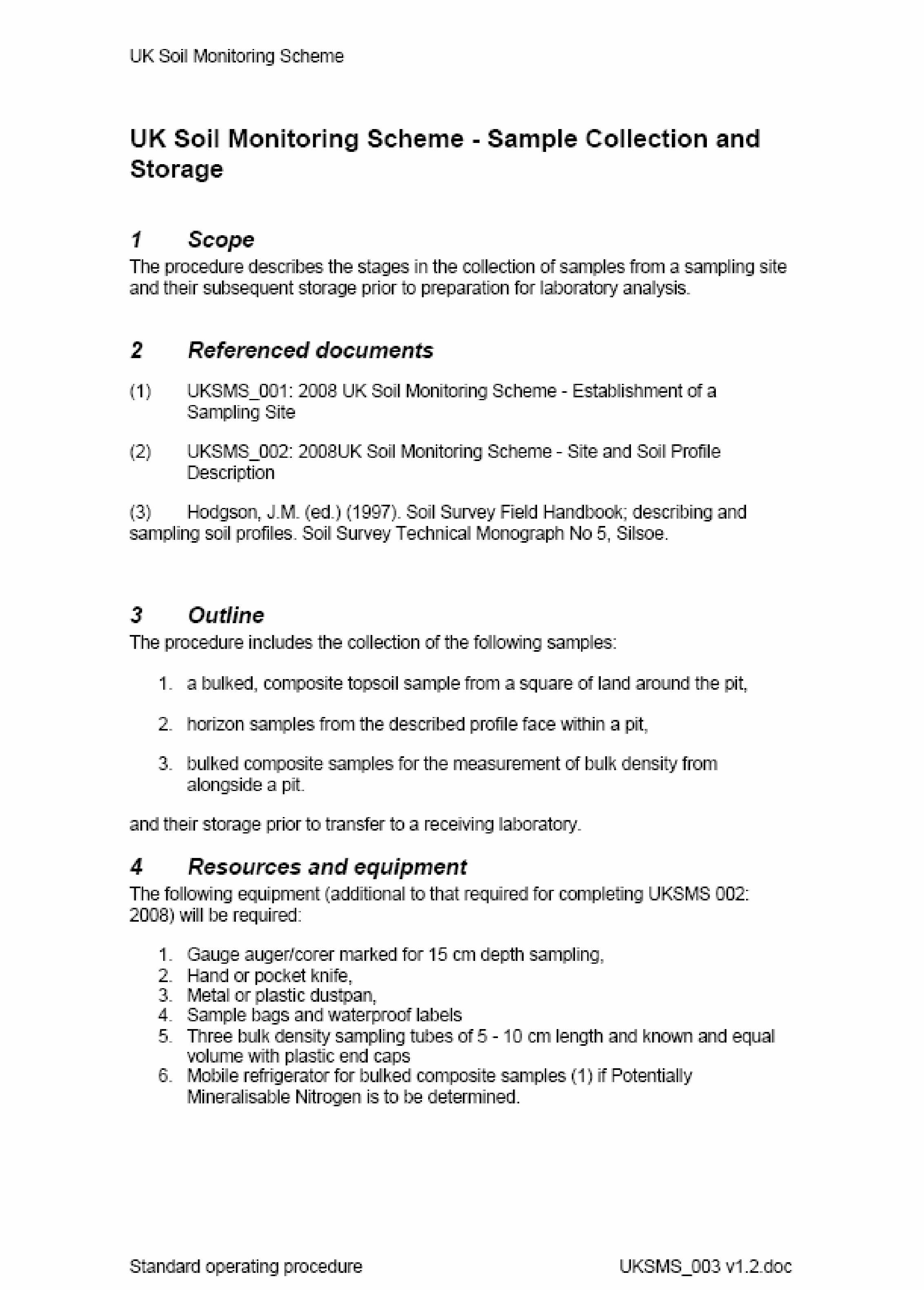
UK Soil Monitoring Scheme - Sample Collection and Storage



UK Soil Monitoring Scheme

Versions

Version No.	Date	Comments
1	29.04.08	First draft
2	08.05.08	Second draft incorporating amendments from Brian Reynolds



UK Soil Monitoring Scheme - Sample Collection and Storage

1 *Scope*

The procedure describes the stages in the collection of samples from a sampling site and their subsequent storage prior to preparation for laboratory analysis.

2 *Referenced documents*

(1) UKSMS_001: 2008 UK Soil Monitoring Scheme - Establishment of a Sampling Site

(2) UKSMS_002: 2008UK Soil Monitoring Scheme - Site and Soil Profile Description

(3) Hodgson, J.M. (ed.) (1997). Soil Survey Field Handbook; describing and sampling soil profiles. Soil Survey Technical Monograph No 5, Silsoe.

3 *Outline*

The procedure includes the collection of the following samples:

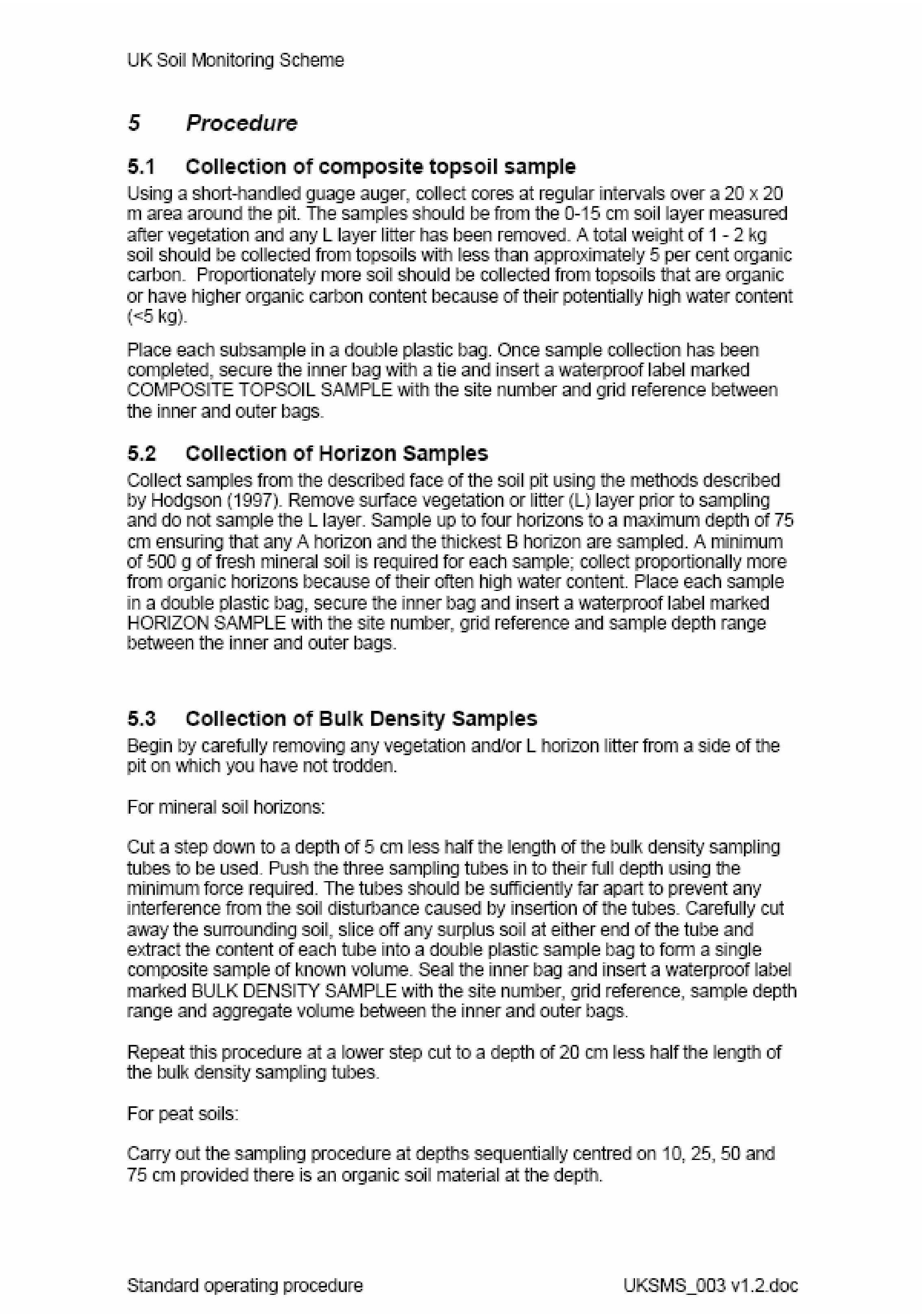
1. a bulked, composite topsoil sample from a square of land around the pit,
2. horizon samples from the described profile face within a pit,
3. bulked composite samples for the measurement of bulk density from alongside a pit.

and their storage prior to transfer to a receiving laboratory.

4 *Resources and equipment*

The following equipment (additional to that required for completing UKSMS 002: 2008) will be required:

1. Gauge auger/corer marked for 15 cm depth sampling,
2. Hand or pocket knife,
3. Metal or plastic dustpan,
4. Sample bags and waterproof labels
5. Three bulk density sampling tubes of 5 - 10 cm length and known and equal volume with plastic end caps
6. Mobile refrigerator for bulked composite samples (1) if Potentially Mineralisable Nitrogen is to be determined.



5 *Procedure*

5.1 Collection of composite topsoil sample

Using a short-handled guage auger, collect cores at regular intervals over a 20 x 20 m area around the pit. The samples should be from the 0-15 cm soil layer measured after vegetation and any L layer litter has been removed. A total weight of 1 - 2 kg soil should be collected from topsoils with less than approximately 5 per cent organic carbon. Proportionately more soil should be collected from topsoils that are organic or have higher organic carbon content because of their potentially high water content (<5 kg).

Place each subsample in a double plastic bag. Once sample collection has been completed, secure the inner bag with a tie and insert a waterproof label marked COMPOSITE TOPSOIL SAMPLE with the site number and grid reference between the inner and outer bags.

5.2 Collection of Horizon Samples

Collect samples from the described face of the soil pit using the methods described by Hodgson (1997). Remove surface vegetation or litter (L) layer prior to sampling and do not sample the L layer. Sample up to four horizons to a maximum depth of 75 cm ensuring that any A horizon and the thickest B horizon are sampled. A minimum of 500 g of fresh mineral soil is required for each sample; collect proportionally more from organic horizons because of their often high water content. Place each sample in a double plastic bag, secure the inner bag and insert a waterproof label marked HORIZON SAMPLE with the site number, grid reference and sample depth range between the inner and outer bags.

5.3 Collection of Bulk Density Samples

Begin by carefully removing any vegetation and/or L horizon litter from a side of the pit on which you have not trodden.

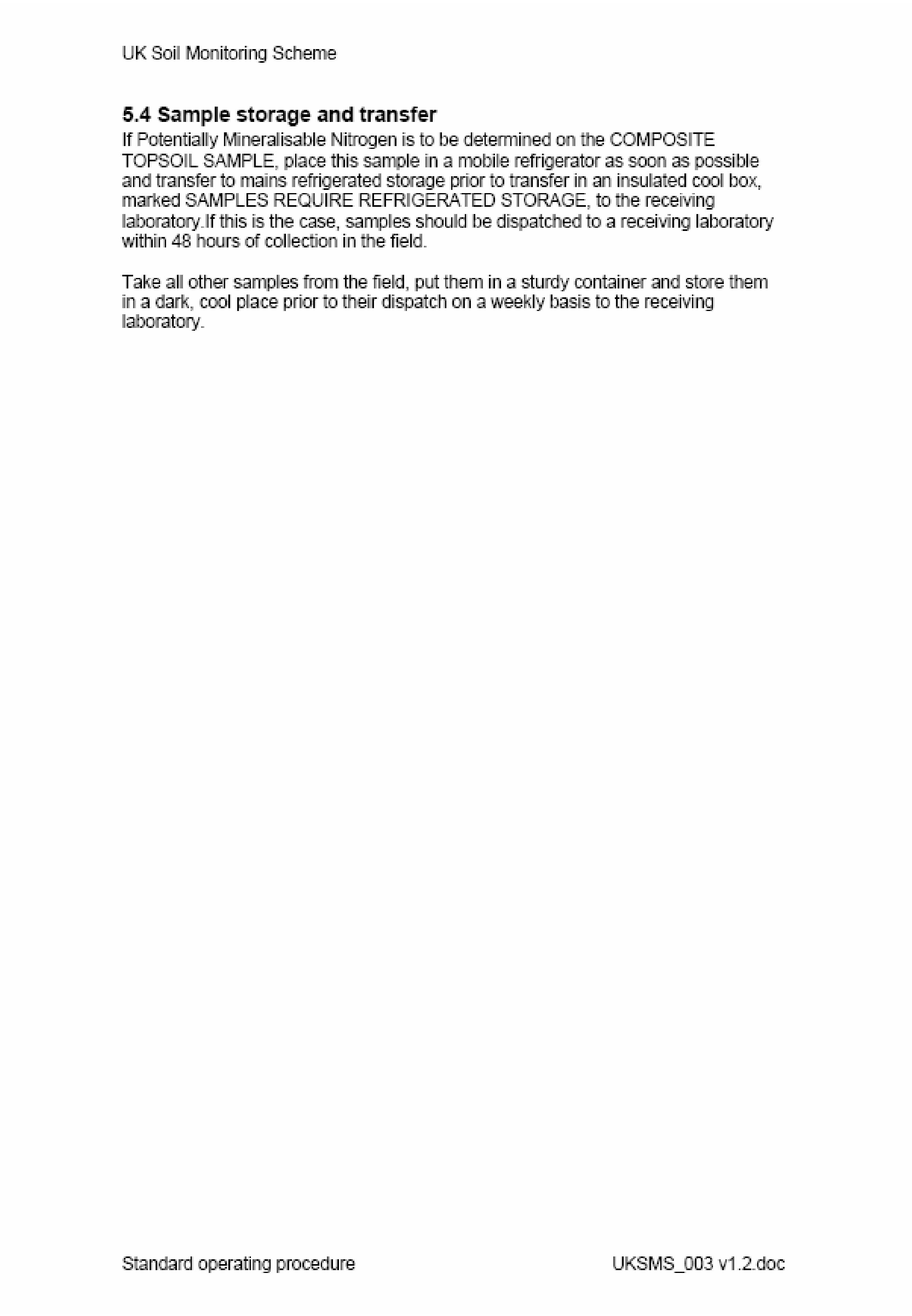
For mineral soil horizons:

Cut a step down to a depth of 5 cm less half the length of the bulk density sampling tubes to be used. Push the three sampling tubes in to their full depth using the minimum force required. The tubes should be sufficiently far apart to prevent any interference from the soil disturbance caused by insertion of the tubes. Carefully cut away the surrounding soil, slice off any surplus soil at either end of the tube and extract the content of each tube into a double plastic sample bag to form a single composite sample of known volume. Seal the inner bag and insert a waterproof label marked BULK DENSITY SAMPLE with the site number, grid reference, sample depth range and aggregate volume between the inner and outer bags.

Repeat this procedure at a lower step cut to a depth of 20 cm less half the length of the bulk density sampling tubes.

For peat soils:

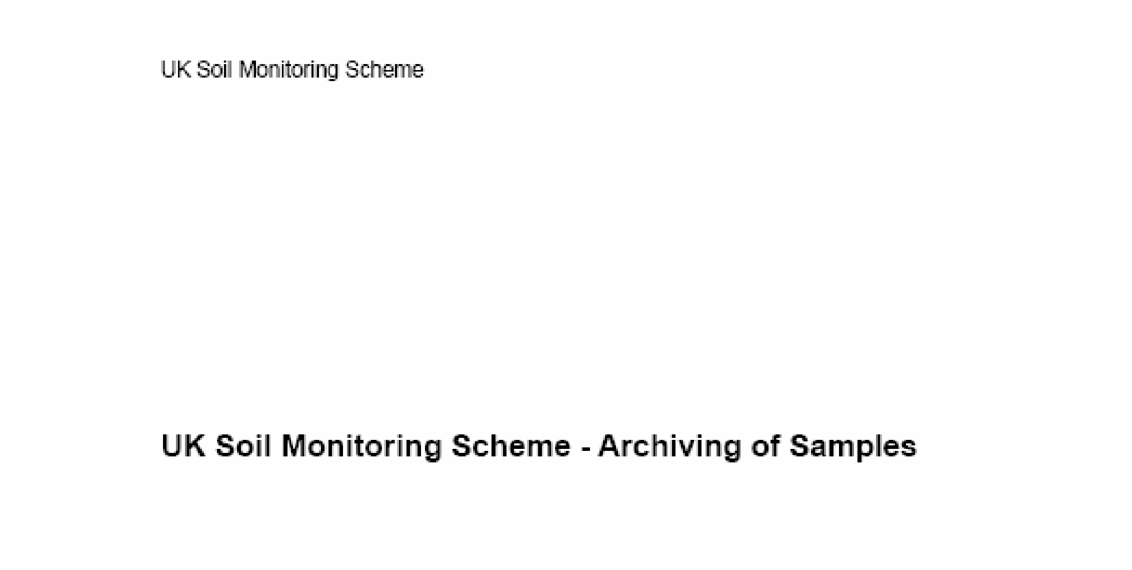
Carry out the sampling procedure at depths sequentially centred on 10, 25, 50 and 75 cm provided there is an organic soil material at the depth.



5.4 Sample storage and transfer

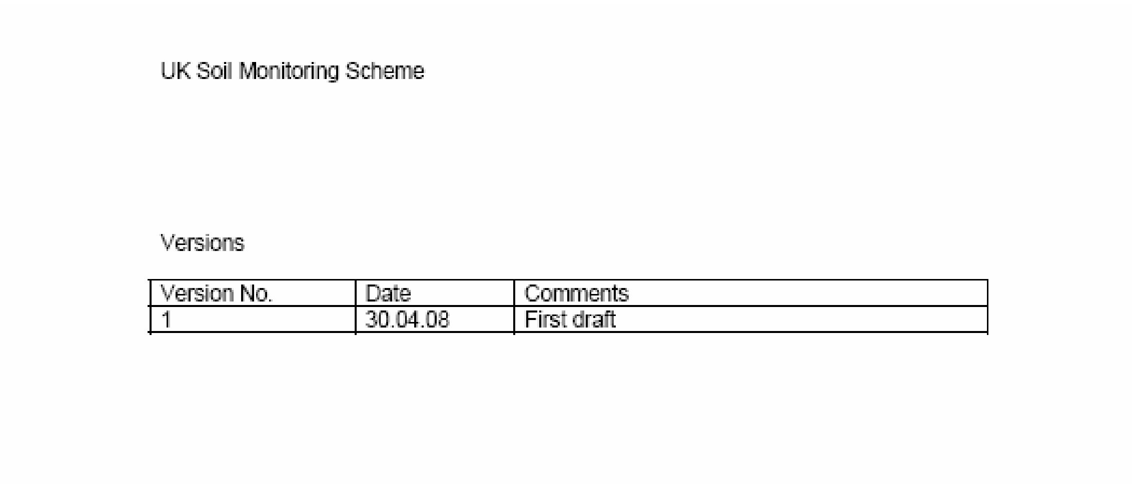
If Potentially Mineralisable Nitrogen is to be determined on the COMPOSITE TOPSOIL SAMPLE, place this sample in a mobile refrigerator as soon as possible and transfer to mains refrigerated storage prior to transfer in an insulated cool box, marked SAMPLES REQUIRE REFRIGERATED STORAGE, to the receiving laboratory.If this is the case, samples should be dispatched to a receiving laboratory within 48 hours of collection in the field.

Take all other samples from the field, put them in a sturdy container and store them in a dark, cool place prior to their dispatch on a weekly basis to the receiving laboratory.



UK Soil Monitoring Scheme

UK Soil Monitoring Scheme - Archiving of Samples



UK Soil Monitoring Scheme

Versions

Version No.	Date	Comments
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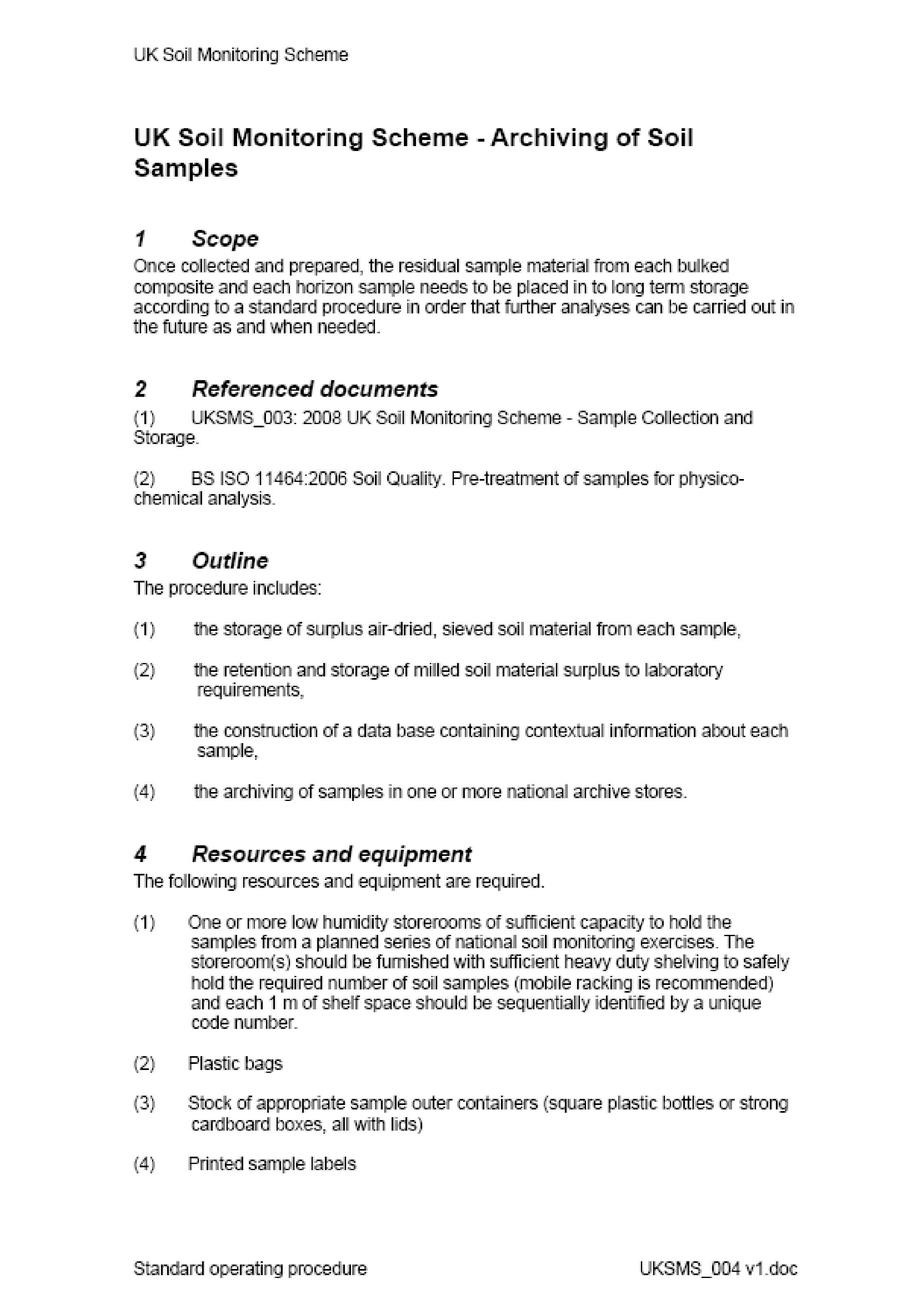


UK Soil Monitoring Scheme - Archiving of Soil Samples

1 *Scope*

Once collected and prepared, the residual sample material from each bulked composite and each horizon sample needs to be placed in to long term storage according to a standard procedure in order that further analyses can be carried out in the future as and when needed.

2 *Referenced documents*

(1) UKSMS_003: 2008 UK Soil Monitoring Scheme - Sample Collection and Storage.

(2) BS ISO 11464:2006 Soil Quality. Pre-treatment of samples for physico-chemical analysis.

3 *Outline*

The procedure includes:

(1) the storage of surplus air-dried, sieved soil material from each sample,

(2) the retention and storage of milled soil material surplus to laboratory requirements,

(3) the construction of a data base containing contextual information about each sample,

(4) the archiving of samples in one or more national archive stores.

4 *Resources and equipment*

The following resources and equipment are required.

(1) One or more low humidity storerooms of sufficient capacity to hold the samples from a planned series of national soil monitoring exercises. The storeroom(s) should be furnished with sufficient heavy duty shelving to safely hold the required number of soil samples (mobile racking is recommended) and each 1 m of shelf space should be sequentially identified by a unique code number.

(2) Plastic bags

(3) Stock of appropriate sample outer containers (square plastic bottles or strong cardboard boxes, all with lids)

(4) Printed sample labels

(5) Bar-code system linked to a database and bar-code printer (adhesive labels). The data base should contain the following fields.

site number; sample type; grid reference; depth range (for horizon samples only); the weight of sieved and of milled soil; the shelf location identifier.

5 *Procedure*

The application of UK SMS_003 (Sample collection and storage) and BS ISO 11464:2006 (Soil Quality. Pre-treatment of samples for physico-chemical analysis) will generate the following subsamples for each bulked composite topsoil sample and each horizon sample:

1. An amount of air-dried, sieved (2 mm) soil (Sample A)

2. For those samples that are prepared for laboratory analysis, a further amount of air-dried, sieved and milled soil (Sample B).

Soil collected for bulk density measurement will be discarded once analysis is complete.

This document describes a procedure for the archiving of paired A and B samples collected at each soil monitoring site.

(1) Seal Sample A in a plastic bag with a duplicate of its sample label marked 'S' (for sieved) and place this bagged sample into an outer container of sufficient size to contain it and the corresponding Sample B.

(2) After all analysis has been completed, any residual milled soil sample (Sample B) should be sealed in a plastic bag with its sample label marked 'M' (for milled) and placed in the outer container with its corresponding Sample A, as a separate subsample.

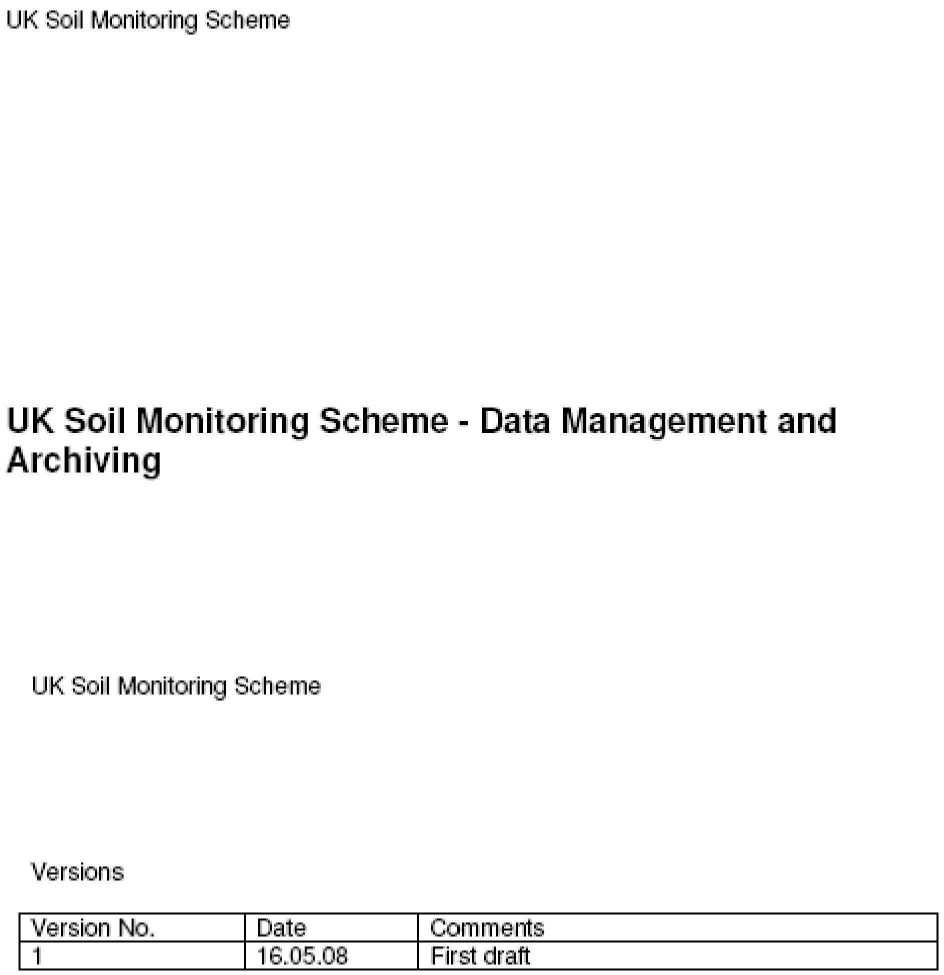
(3) Weigh each of the samples and record their individual net soil weight.

(4) Enter the sample identity details (site number, sample type, grid reference, depth range (for horizon samples only) and the weight of Sample A and Sample B) into the bar-code data base and print off an adhesive bar-code label.

(5) Attach the bar code label to the outer container and place the container on a shelf. Record the shelf location in the bar code data base.

6 *Outcomes*

The procedure will result in the long term safe storage of soil samples from the national monitoring programme in one or more consistently and adequately documented soil sample archives.



UK Soil Monitoring Scheme

UK Soil Monitoring Scheme - Data Management and Archiving

UK Soil Monitoring Scheme

Versions

Version No.	Date	Comments
1	16.05.08	First draft

UK Soil Monitoring Scheme - Data Management and Archiving

1 *Scope*

This Standard Operating Procedure ensures a consistent approach to the reception, management, organisation, security, analysis, presentation/output and archiving of all data associated with a UK soil monitoring exercise in adherence to appropriate existing data management standards. It will facilitate the potential interoperability of the data gathered together with other parallel data resources and similar data themes from geographically distinct regions.

2 *Referenced documents*

(1) UKSMS_001: 2008 UK Soil Monitoring Scheme - Establishment of a Sampling Site

(2) UKSMS_002: 2008UK Soil Monitoring Scheme - Site and Soil Profile Description

(3) UKSMS_003: 2008 UK Soil Monitoring Scheme - Sample Collection and Storage

(4) UKSMS_004: 2008 UK Soil Monitoring Scheme - Archiving of Samples

(5) European Commission (2007) ' Directive 2007/2/EC Infrastructure for Spatial Information in the European Community (INSPIRE). Official Journal of the European Union L 108/1.

(6) DNF (2008) Coordinate Referencing Systems & Transformations. Component 1.3 Technical Guide. Document DNF 0020. Online at http://www.dnf.org/Pages/technical%20guidance/technicalguides.asp. Accessed 16/5/08.

(7) UK Gemini: ISO 19115:2003 Metadata standard proposed element set (draft for public consultation). http://www.gigateway.org.uk/metadata/pdf/ISO19115ProposedElements.pdf

3 *Outline*

The procedure includes the following steps:

1. Design of a UK Soil Monitoring Scheme database to hold all field, site, soil profile, sample and analytical data

2. Design and establishment of hardware and software infrastructure (Soil Monitoring Information Facility) to ensure the secure and successful management and archiving of the database with provisions for access to and reporting of the data in accordance with national and international requirements

3. Population of the database with verified and validated data from field, soil store and laboratory sources

4. Creation of metadata descriptions of the database.

4 Resources and equipment

The following equipment will be required:

1. Appropriate technical infrastructure

5 Procedure

5.1 Design of a UK Soil Monitoring Scheme Database and Information Facility

List comprehensively all data fields to be included in the database. This will include all data from the Field Description Proforma (UKSMS_002:2008) including all data relating to the identity of samples collected, all laboratory data relating to samples that are analysed and the storage location and identify of all samples that are archived (UKSMS_004:2008).

Communicate with the UK Soil Indicators Consortium or equivalent bodies within Government to agree on precise data export and reporting requirements and the levels of access to be given to identified user groups (consistent with appropriate legislation). These discussions should include international obligations, such as INSPIRE (European Commission 2007), as well as national reporting requirements and structures.

Using appropriate software, design and create an electronic storage and retrieval system (data base) such that site, soil physical, chemical and biotic characteristics (field recorded and laboratory analytical data) are captured and can be cross-referenced to each other and to stored physical samples as appropriate, interrogated, and the required reports or raw data exported. A review of alternative soil profile database structures and provisional recommendation for an emergent new standard for soil profile databases is provided by Baritz and Eberhardt (2008).

Design aspects relating to the transmission of the geospatial components of the Soil Monitoring Network over the Internet should reflect the appropriate Open Geospatial Consortium (OGC) web-based services using Geography Markup Language (GML), for instance Web Map Services (WMS) and Web Feature Services (WFS) (OGC, 2008). Geographical coordinates should be expressed in accordance with the recommendations of the Digital National Framework (DNF) Component 1.3 Technical Guide (DNF, 2008).

Draft a written, costed specification for the Soil Monitoring Information Facility detailing the required:

1. technical specification for hardware and software,
2. service to be delivered (data input, validation, analysis (including with pre-existing data sets), access and output) and standards to be complied with,
3. data and system security standards and archive procedures,
4. staffing competencies and levels.

5.2 Establishment of UK Soil Monitoring Scheme Database and Information Facility

Communicate with the UK Soil Indicators Consortium, equivalent bodies within Government or the contracting organisation(s) to agree the physical location(s) and responsible organisation(s) that will host the data base facility(ies).

[It is assumed that contract(s) will be let for the delivery and operation of a facility that meets the specification from $5.1 above]

5.3 Population of the database

Place data into the database from field recording equipment and laboratory/sample store information systems.

To validate and verify entered data use appropriate techniques including:

1. use of cartographic tools to ensure correct geo-positioning of site and sample locations,
2. use of bounds-checking to ensure data entered are within correct nominal ranges,
3. use of appropriate validation and verification tools to ensure correct matching of field sample and laboratory record identifiers.

5.4 Metadata

Establish metadata describing the data content of the database according to ISO 19115:2003 (UK Gemini) which provides a metadata standard proposed element set.

7 Bibliography

Baritz, R. and Eberhardt, E (2008) Environmental Assessment of Soil for Monitoring (ENVASSO): Deliverable 5, Database Design and Selection.

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Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

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