

**An assessment of potential soil indicators for the
preservation of Cultural Heritage.**

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Contents

Summary

1. Background	1
1.1 Project aim	
1.2 Project Background	
2. Soils and Cultural Heritage Preservation	2
2.1 The Cultural Heritage Resource	2
2.2 Soils and the Archaeological Resource	
2.2.1 Soils and Archaeological Preservation	3
2.2.2 Threats to the Archaeological Resource	3
2.3 Soils and Cultural Landscapes	
2.3.1 Soils in Cultural Landscapes	5
2.3.2 The role of soils in the preservation of cultural landscapes	6
2.3.3 Potential threats to the ability of soils to preserve cultural landscapes	6
2.4 Issues of Monitoring Soil Change in Relation to Cultural Heritage	
2.4.1 Sampling schemes	7
2.4.2 Timescale of change	8
2.4.3 Threshold values	8
2.4.4 Scales of monitoring	8
3. Identifying and Testing Indicators	
3.1 Identifying Potential Indicators	10
3.2 Criteria for Testing Indicators	10
4. Assessing the Relevance of Candidate Indicators	
4.1 Indicators of Change in Pressure on Soil Quality	12
4.1.1 Land use change	13
4.1.2 Arable agriculture	13
4.1.3 Grazing	14
4.1.4 Forestry	14
4.1.5 Mineral Extraction	14
4.1.6 Development	15
4.1.7 Recreation	15
4.2 Indicators of Change in Soil Properties and Processes	16
4.2.1 Erosion	16
4.2.2 Soil wetness/watertable depth	18
4.2.3 Oxidation potential	18
4.2.4 Soil organic matter	19
4.2.5 pH	19
4.2.6 Biological activity	19
4.2.7 Conductivity	20
4.2.8 Pollutant loadings	21
4.2.9 Compaction	22
4.3 Potential Headline Indicators	22

5. Testing Proposed Indicators	24
5.1 Area of new cultivation	24
5.2 Depth of ploughing	25
5.3 Area & volume/depth of superficial deposits removed by mineral extraction	26
5.4 Erosion	27
5.5 Water table level/fluctuations	29
5.6 Redox potential	30
5.7 Soil organic carbon	32
5.8 pH	33
5.9 Soil moisture	34
5.10 Phosphate	35
5.11 Compaction/Bulk density	37
6. Recommendations	
6.1 Recommended Headline Indicators	38
6.1.1 Currently practicable	38
6.1.2 Currently impractical	38
6.2 Gaps in knowledge	39
6.3 Potential regional and site-level indicators	39
7. Acknowledgements	39
8. References	40
Appendix 1	Persons and organisations consulted
Appendix 2	Pressures, threats, responses and potential impacts on the cultural heritage resource
Appendix 3	The impact of selected threats to the cultural heritage resource
Appendix 4	Summary table of potential indicators and criteria scores

Summary

The UK has a rich and diverse cultural heritage resource which includes landscapes and landscape elements, standing monuments, buried archaeological sites, artefacts, environmental remains and soils. Soils play an important role in the preservation of this resource, but they are also the medium for its inevitable degradation in response to natural and anthropogenically driven soil processes. However, whilst the loss of cultural information may be irreversible, anthropogenic pressures and soil conditions may be manipulated to slow degradation and promote preservation.

This report aims to identify and assess potential indicators of change in soil quality for the function of cultural heritage preservation. Indicators were assessed on their relevance, sensitivity, practicability, efficiency and cost, and integration. Recommendations of potential indicators are based on the outcomes of this testing.

A consultation exercise associated with this report identified arable agriculture and forestry, development and mineral extraction as the major pressures negatively affecting soils ability to preserve cultural heritage. In particular ploughing, erosion, dewatering, declining soil organic matter and changes in soil fertility were identified as the most damaging soil processes.

There is clear need for a monitoring scheme to identify potentially damaging soil changes and inform national policy. However, the irreversibility of cultural heritage information loss makes it important that national level policy filters rapidly down to regional and site-specific level management initiatives. A tiered approach similar to that proposed by Merrington et al (2006) is recommended with regional and site level monitoring with a range of indicators where specific threats are identified on the basis of national level, headline indicators. Threshold values commonly used in monitoring schemes are not felt to be relevant because they take no account of the historical soil / resource equilibria. Change relative to modern baseline soil values would be the most practicable way of assessing and interpreting data. Changing patterns of land use and climate data should also be considered in the interpretation of headline indicators.

Soil organic carbon content and pH are identified as relevant and currently practicable, and hence are recommended as headline indicators. Area and volume / depth of superficial deposits removed by mineral extraction could also be a relevant indicator with some development. Many potential indicators identified as highly relevant to cultural heritage preservation are not currently practicable because of the level of current technology, lack of baseline soil data and / or a lack of knowledge about the response of the resource to monitored changes. This group includes erosion (including tillage erosion and peat wastage), plough depth, and dewatering, and each warrants further research with the aim of developing indicators.

Other gaps in our knowledge include an understanding of landscape level responses to changes in soil fertility, drainage, chemical and biological properties, the effects of fertilisers and pesticides on buried artefacts, threats to archaeological monuments in non-arable areas, the role of microbial activity in cultural material degradation, and the role of pedogenic thresholds and time in the response of cultural material to soil change. There is also a general paucity of UK wide baseline data.

1. Background

1.1 Project Aim

The aims of this study are to:

1. Identify and assess potential indicators to monitor the function of soils in preserving archaeological and cultural heritage resources and landscapes.
2. Apply robustness testing to the candidate indicators.
3. Recommend a sub-set of potential indicators that may be worth further testing.
4. Identify gaps in the current knowledge of the threats to the resource and its response to changes in identified indicators, the availability of base-line data, and suitable monitoring methodologies and instrumentation.

The indicators are intended for monitoring national level future changes in soil quality which have a detrimental impact on the archaeological and cultural landscape resource. They are not designed to provide an assessment of the current state of the resource or to monitor directly the consequences of soil change on that resource, nor are headline indicators designed for use in regional or local-scale monitoring although their potential application at smaller scales is discussed. Coastal erosion and sea-level change are not in the remit for this study.

1.2 Project methods

The primary methods employed in this project are literature search and consultation with key stakeholders and interested parties. Consultation with persons involved with cultural heritage was undertaken during the initial background gathering exercise and a working draft of the report was also sent out to this group for feedback at an earlier stage of the project (stage 3). Consulted persons are listed in Appendix 1.

The project consisted of 4 distinct phases.

Stage 1 - Background setting, involving literature review and consultation.

Stage 2 - A review and collation exercise assessing candidate measures and their likely potential value as indicators of cultural heritage preservation.

Stage 3 - An assessment of candidate indicators for their relevance, robustness and sensitivity, practicability, and cost, in order to propose a sub-set of candidate indicators.

Stage 4 - Consultation and validation of candidate indicators through feedback from the Soil Indicators Consortium (UK SIC).

2. Soils and Cultural heritage preservation

2.1 The cultural heritage resource

The UK landscape preserves a rich and diverse record of our cultural heritage that dates back almost half a million years. It is easy to underestimate the UK's cultural heritage resource in terms of its economic and social importance. However, recently the impact of this resource on tourism, education, regional identity and quality of life has begun to be recognised and quantified as indicated in The London Declaration (2004) which states:

"Cultural heritage... has considerable impact in many areas of economic and regional development, sustainable tourism, job creation, improving skills through technological innovation, environment, social identity, education and construction."

The importance of protecting the cultural heritage resource has been recognised in PPG15, PPG16 and The Valletta Convention (1992) however these regulatory measures are concerned primarily with the threat from development.

The UK's cultural heritage includes a range of deposits, materials, monuments, landscapes and landscape units. For example:

- Archaeological monuments (physical constructions), both at the surface and below.
- Archaeological stratigraphies and deposits, which provide the soil matrix and give context to monuments, artefacts, and environmental remains.
- Artefacts, including worked flint and other stone, ceramics, coins and other metal objects, textiles, artefacts made from bone, horn, wood, leather etc.
- Landscapes and landscape units (ancient and managed woodland, field systems, lakes, traditional land management systems, buildings, upstanding monuments etc.).
- Archaeological soils and sediments (including peat, palaeosols and 'plaggen' soils), which preserve the legacy of past land management practices in their physical structure, magnetic susceptibility, biogeochemistry and fertility.
- Plant and animal remains including pollen, diatoms, invertebrates, lipid and other biochemical residues.

The cultural resource consists not only of known sites, of which Darvill and Fulton, 1998 estimate there are 600,000 in England alone, but also unidentified buried remains. Areas of peat, alluvial and estuarine sediments, colluvium and made ground have particularly high potential for archaeological preservation (Van de Noort, 2001).

Both soils and sediments may contain important cultural information, form the matrix for buried cultural heritage, and are an important part of the cultural landscape. Hence, it is important that both soils and sediments are included in any monitoring scheme and henceforth in this document reference to 'soil' or 'soils' should also be taken to include sediments.

2.2 Soils and the archaeological resource

2.2.1 Soils and Archaeological Preservation

The function of soils in relation to cultural heritage preservation is unlike that of most other soil functions for two reasons. Firstly, the cultural resource is non-renewable. The effects of processes of soil-mediated decay and destruction on archaeological resources are unidirectional without the possibility of remediation. Those soil conditions promoting preservation or destruction may, however, be manipulated. Secondly, soils themselves are part of the cultural record and anthropogenically mediated soil changes are part of this record.

The relationship between soil and the archaeological resource may be better described as historical survival rather than preservation. The nature of any archaeological entity is a legacy that has survived by approaching, but never reaching, equilibrium with historical (and prehistoric) soil conditions. Natural degradation and loss of cultural information is an unavoidable fact. However, changes in soil conditions driven by anthropogenic factors such as land use and climate change can affect the quasi equilibrium resulting in an acceleration of decay processes or even a change in the very nature of these processes.

If soil processes change, previously well preserved material may degrade more rapidly (Table 2). This is particularly important for materials that are usually sensitive to degradation (e.g. organic matter, skin, textiles, etc.). If waterlogged sites are affected by falling watertables these important and relatively rare materials may be very rapidly lost.

Our knowledge of how archaeological resources respond to changing soil properties is fragmentary and predicting responses and the impact of complex changes is difficult. For example, dewatering may lead to any or all of the following; shrinkage and erosion of deposits, oxidation, increased biological activity, increased acidity, corrosion of artefacts.

Research into taphonomic processes (the conditions and processes of post-depositional preservation and degradation) varies according to resource; for example, the response of bone (Millard, 1998; Jans et al. 2002; Nord et al, 2005) and metals (Tronner et al. 1995; Nord et al, 2005) to the burial environment, and the effect of cultivation on surface and shallowly buried archaeological deposits and artefacts (Oxford Archaeology, 2002) have been relatively intensively researched. However, the effects of dewatering, chemical contamination, surface sealing etc. are generally less well understood.

2.2.2 *Threats to the archaeological resource*

Appendices 2 and 3 summarises some of the pressures and threats to the cultural heritage resource, and the potential impact on the resource of these changes. Threats include:

- Changes in land use and management, for example from grazing to arable or forestry,
- Agricultural and forestry processes including ploughing, drainage, liming and harvesting,
- Urban and rural development and redevelopment,
- Mineral extraction and peat cutting,
- Climate change.

Table 2: Preferential conditions soil conditions (pH, drainage and oxidation) for preservation of different archaeological material, based on English Heritage (2002).

	Likelihood of survival	Drainage and oxidation	pH	Comments
Stratigraphy	**	Waterlogged	Strongly acid or strongly alkaline	Preservation aided by deep, rapid burial below fine textured sediments.
Wood	**	Waterlogged and anaerobic, or dessicating	Acid to Alkaline	
Plant remains	*	Waterlogged and anaerobic, or dessicating	Acidic	
Seeds	*	Waterlogged and anaerobic, or dessicating	Acidic to Neutral	
Charred organic remains	**	Waterlogged and anaerobic or dessicating	Acidic to Neutral	Preservation affected by charring conditions.
Pollen	**	Waterlogged and anaerobic	Acidic	May survive in acidic oxic environments, survives well in anaerobic, acidic environments
Molluscs	*	Waterlogged and anaerobic	Alkaline > pH7	May survive in oxic alkaline conditions, and neutral soils.
Insects	*	Waterlogged and anaerobic	Acidic to neutral	
Bone	**	Waterlogged and anaerobic, or dessicating	Neutral or alkaline	Survival affected by pre-burial treatment, species and size
Skin	*	Waterlogged and anaerobic or dessicating	Acid	
Leather	**	Waterlogged and anaerobic, or dessicating	Acid to moderate basic	
Textiles	*	Waterlogged and anaerobic, or dessicating	Neutral or moderately alkaline	
Ceramics	***	Anaerobic or dessicating	All	Neutral or alkaline conditions favour low-temperature fired materials.
Iron	**	Anaerobic	Neutral or alkaline	
Copper	***	Anaerobic	Neutral or alkaline	
Glass	***	Anaerobic or dessicating	Neutral or alkaline	Roman glass highly resistant, Medieval glass is less resistant to decay
Plaster and Mortar	**	Anaerobic or dessicating	Neutral or alkaline	

Likelihood of survival refers to moderately acid, moderately drained soil conditions.

* poorly resistant - rarely survive; ** moderately resistant; *** highly resistant - usually survive.

NB. all materials are susceptible to physical damage in the ploughzone

These pressures occur against a background of natural on-going degradation of the resource. True equilibrium with the burial environment is rarely reached, and the effects of natural climatic variability can have devastating impacts, particularly with respect to erosion and lowering of water tables. The rate of natural degradation is influenced by the nature of the resource and the prevailing soil conditions in particular soil wetness, pH, oxidation status and whether the surface is eroding or aggrading.

The consultation process undertaken in the development of this report led to the identification of the following major current pressures on the archaeological resources:

- 1, Arable agriculture
- 2, Mineral extraction and its effect on water table levels
- 3, Development and soil sealing

The most significant impacts arising from these threats were felt to be:

- 1, Erosion (including sediment redistribution) and plough damage, which cause physical damage to cultural remains and landscapes and destroy the stratigraphic context for artefacts and ecofacts.
- 2, Dewatering and associated changes in soil moisture regimes and redox conditions; changes to more oxidising conditions are a particular threat to the survival of fragile organic materials and pollen.
- 3, Changes in soil and groundwater quality, particularly pH, through atmospheric deposition, land use and land management practices, and changes in drainage which can lead to increased degradation of certain types of artefact.
- 4, Loss of soil organic matter. Soil organic matter can be an archaeological resource in its own right, preserving evidence of past land management activities and its degradation results in loss of information. Soil organic matter is also important in stabilising soils. A lowering of soil organic matter can leave soils more susceptible to erosion.

In the mid to longer term soil and land use changes driven by climate change were also felt to be a significant threat to cultural heritage preservation.

2.3 Cultural landscapes

2.3.1 Soils in cultural landscapes

In the UK our constantly evolving landscape is a function of both the natural and cultural environment, the influence of the latter stretching back into prehistory. The whole of the UK landscape has been shaped to some extent by a history of human land use; in essence there are no purely 'natural' landscapes in the UK. The result is a modern landscape that has developed over time that may preserve a mixture of elements from multiple former phases of cultural activity stretching back into prehistory. The cultural element includes patterns of land use – including designed landscapes, buildings and other structures, and upstanding archaeological monuments (SNH, 2003; Scotland's future landscapes?). However, the interaction between the 'cultural' and 'natural' elements of landscape should also not be forgotten as the legacy of past human interventions can affect landform, drainage patterns and vegetation types.

At a national level preserving and enhancing the diversity of landscape types is possibly the most important factor in the preservation of cultural landscapes, though at a local and regional level many individual landscape types – including lowland agricultural, coastal and upland landscapes - are under threat (Thin, pers. comm.). Soil properties, such as drainage, fertility, and frequency and type of cultivation, are important in defining the patchwork of landscape types.

2.3.2 The role of soils in the preservation of cultural landscapes

The role of soils in the development of cultural landscapes is varied. Soils may:

- Act as a basis for past, present and future agriculture. For example, the survival of the Bronze Age Dartmoor reave field systems reflects past socio-economic and soil conditions. Modern agricultural systems may be based on fertile soils that are the result of past land management practices, for example, the deepened topsoils around Scottish burghs (Golding and Davidson, 2005).
- Act as a basis for habitat/ecosystem support – The past, present and future ability of soils to support those landscape features and habitats that directly or indirectly result from past human intervention. For example, the landscape of the Norfolk Broads is the product of Medieval and Post-Medieval peat cutting, agriculture, and drainage. However, the Broads landscape has been under considerable threat from changes in agriculture, drainage and peat wastage (Murphy, 2001).
- Influence the sensitivity of landscapes to erosion and sediment redistribution. Past soil erosion and valley sedimentation has been an important factor in shaping landscape.
- Themselves may form part of the cultural landscape, for example, as redeposited tips of spoil resulting from mining, quarrying, and other industrial activities, or the patchwork of relatively fertile soils associated with former habitation in today's marginal landscapes.

2.3.3 Potential threats to the ability of soils to preserve cultural landscapes

Current threats to cultural landscapes in England and Scotland (Countryside Agency, 1999; Scottish Natural Heritage, 2002) include:

- Changing agricultural practices,
- Forestry,
- Energy generation,
- Development and redevelopment,
- Mineral extraction and restoration,
- Radio, phone masts and pylons
- Climate change,
- Over abstraction of river and stream waters,
- Recreation, tourism and through traffic

Many potential threats are regional in nature, for example, the loss of traditional hop gardens and orchards in the North Kent Plain (Countryside Agency, 1999). Threats to changes in the English landscape are being monitored through the Countryside Quality Counts (CQC) Project, aimed at bringing different sources of information together, which is being used to track change across the Character Areas of England.

The threat these activities pose to the cultural landscape include direct physical changes to the landscape through changing land use, agriculture and land management, alteration or removal of field boundaries, and destruction of archaeological monuments. However, there may also be indirect effects. Manuring, drainage, physical destabilisation, reduction in SOM, and changes to soil structure, chemistry and biology can affect fertility or increase erosion, affecting the ability of soil to support 'cultural' ecosystems and habitats.

The most significant impacts arising from these threats were identified as:

- Erosion
- Dewatering
- Increases or decreases in soil fertility for agriculture arising from cropping, fertiliser application, drainage, liming, and other amendments.

2.4 Issues of monitoring soil change in relation to cultural heritage

There is a general perception that there is insufficient baseline data on soil quality to inform national policy (e.g. Environment Agency, 2004: The state of soils in England and Wales), and in particular on the current state of the UK's cultural heritage and the impact of soil change. This means that there is a high potential return from a new national-level monitoring scheme. However, the extensive gaps in our knowledge of the current state of the resource, historical levels and rates of change, and the response of the resource to change also present significant challenges to the development of such a scheme. The gathering of baseline data (new and old), the choice of indicators, and the design of the sampling and monitoring scheme will be hugely important to the outcome of this project.

2.4.1 Sampling schemes

The high cultural potential of deeply buried deposits means that it is important that monitoring is not restricted to known sites, hence a wider monitoring programme is required than one based purely on site by site assessment. Accounting for the heterogeneity of the soil, landscape and archaeological resource in a cost-realistic way is likely to represent one of the greatest sampling challenges to any monitoring programme. Random sampling and grid sampling schemes are unlikely to fully address these issues as they may miss areas of cultural heritage interest. Many national-level monitoring schemes use the 1:250,000 national soil map as a basis for sampling. Such an approach would take account of dominant soil process and geology. However, soil units provide less information about the sedimentary history. The depth of Holocene deposits, and hence archaeological potential, will be an important factor in identifying areas of high currently unknown archaeological potential and in designing a monitoring scheme that will take account of changes affecting the buried resource. This information is available from the British Geological Survey.

Alternative approaches might include a catchment-based approach whereby erosion or sedimentation balance could be used as a basis for monitoring. Landscape character assessment units (Swanwick, 2002) including urban areas could also provide a basis for monitoring cultural landscape, and historic landscape assessments might provide some of

the much needed time depth element, but although soils are indirectly incorporated into these units, it is not explicit enough for monitoring soil change directly. A combination approach may be needed based on 'risk', similar to that used by Oxford Archaeology (2002) in their assessment on the management of archaeological sites in arable landscapes. For some indicators, such as soil organic matter (Merrington, pers. comm.), reference sites may also be required to interpret soil change and to set thresholds.

Depth of monitoring should be considered carefully to ensure that conditions relevant to unidentified, deeply buried resources are assessed. Suitable monitoring depths or depth increments will need to be carefully considered for each indicator and with reference to specific monitoring sites.

Existing monitoring schemes such as the Countryside Survey and Forestry Commission soil monitoring plots could be included, but only where the analytical techniques and sampling points fit cohesively within the final monitoring framework.

2.4.2 Timescale of change

The irreversible nature of archaeological degradation means that timescale for monitoring is uniquely important. If the measurement interval for any particular indicator is too long it may mask significant changes resulting in permanent loss of information. Currently, not enough is known about the timescale of change and degradation in respect to cultural heritage resources. To be policy-relevant it is important to be able to resolve anthropogenically driven change from natural changes. Monitoring frequency should also take account of the potential for thresholds associated with rapid change and interspersed by periods of relative stability (Chadwick and Chorover, 2001). It must also be clear whether it is the change-event (e.g. changes in the area of cultivation or woodland) or the consequences in terms of cultural resource degradation that are being monitored.

2.4.3 Threshold values

For an indicator to be useful, threshold values are required to provide meaning as to the likely response of the resource to any given degree of change. The setting of threshold or trigger values is contentious as values vary according to soil type and land use (Merrington et al. 2006). The New Zealand soil indicators project (SINDI), for example, uses expert judgement through a Modified Delphi Technique to derive response curves and set trigger values (Sparling et al. 2003; Tarbotton and Sparling, 2003).

With respect to cultural heritage change, it is not relevant to monitor change relative to absolute threshold values. The buried cultural resource as it survives today has done so by approaching equilibrium with dynamic soil conditions. Cultural landscapes are also evolving and a certain degree of necessary and inevitable change has to be expected and accepted. In practice, measuring change relative to current soil conditions and / or contemporary reference profiles may be the most practical means of setting threshold values. This approach would need to include reference profiles and baseline data against which changes can be measured.

2.4.4 Scales of monitoring

This report proposes indicators of change that can be used to inform national-level policy decisions. Archaeological preservation issues have traditionally been considered at a site-

specific level and site based monitoring and it is important that there is some means of ensuring that this national level monitoring trickles down to also inform regional and site-based issues. The importance of site-based monitoring schemes is something that has been stressed by many of the archaeologists consulted during this project.

The approach recommended by Merrington et al. (2006) for soil indicators of environmental interaction is that of a tiered approach:

1. Broad-scale monitoring with data collected using the headline soil indicators across the UK. Generic information is collected on the state of UK soils to identify headline trends and areas at risk. At this level existing data on soil properties can be used to broaden the data set and enable identification of trends.
2. More specific monitoring using a more targeted set of indicators for sites identified through the use of triggers at tier 1, or through the use of a risk-based approach.
3. Refines the information collected to answer localised issues. The type and magnitude of the issue would dictate the type of monitoring carried out.

Because of the irreversibility of cultural information loss there is a need for national level policy to filter rapidly down to regional and site-specific level management initiatives. A similar risk-based, tiered approach would be worth considering for cultural heritage preservation. Tier 1 would be headline national level monitoring. Tier 2 would be a landscape / resource specific scheme, and tier 3 would monitor change at the 'site' level where specific, significant risks have been identified at tier 1 and 2.

At each tier or level, the indicators used would need to be reviewed to take account of regional and site specific conditions and threats. As such, individual site level monitoring may consist of a very different suite of indicators and methods than that used at the national level, and may also include the greater use of proxy indicators and measures of site 'condition'. Whilst we have sympathy for the view of some archaeologists that monitoring should be site-based, we do feel that a top down monitoring programme such as that proposed above is more appropriate than one based at the site-level because of:

- The problems of extrapolating from site-specific data without a properly established sampling framework.
- The difficulties of bringing together a host of site-specific indicators into a single useable database.
- The potential favouring of known, and possibly scheduled, sites and the resultant resource and spatial biases.

3. Identifying and Testing Indicators

Indicators may include direct measures of soil change, proxy indicators of soil change, or measures of the response of the cultural resource. This latter group was excluded from this exercise as it measures only the known resource and it was found to be difficult to correlate degradation in the resource directly with soil changes. Proxy measures of soil change are often harder to interpret as they usually involve a number of different processes, hence direct measures are preferred. However, in some cases proxy measures may be easier to monitor and hence are considered where direct means are unavailable or impractical.

3.1 Identifying potential indicators

To identify potential indicators, soil processes linked to known pressures were rated subjectively according to their potential impact of the resource. These were then linked to those soil properties and other potential indicators that may indicate change in the process or a response by the soil to such changes. The aim was to identify indicators linked to one or more of these processes to test against the criteria in section 3.2

3.2 Criteria for Testing Indicators

Each indicator was tested against five key criteria. Potential indicators were either failed outright or graded between 1 (poor) and 3 (good) against each criterion. If an indicator failed any one step outright, it was excluded from further consideration. Key criteria (and the order) for testing the indicators are:

1. Relevance and interpretability

Indicators must be relevant to the function of cultural heritage preservation and interpretable in quantitative terms as an indicator of soil quality and the temporal changes in soil quality. It must be clear what interpretation can or cannot be placed on an indicator and whether they are direct or indirect indicators of soil quality. The score also reflects the likely impact of soil changes being monitored by the proposed indicator on the cultural heritage resource.

2. Sensitivity, discrimination and signal-to-noise ratio

Long-term monitoring must attempt to discriminate long term trends from noisy backgrounds. Indicators must consider the probability of detecting significant changes over the sampling intervals. Indicators that are unlikely to detect significant changes over reasonable time scales because of high background variability should not be chosen. Indicators should be evaluated against the time span over which significant changes will go undetected. This is particularly important for cultural heritage preservation as changes are irreversible.

3. Practicability

Are there robust, proven methods of analysis? Are such methods in the pipeline? Or will they need considerable development?

4. Efficiency and cost

Indicator choice should seek to maximise the use of automatic sensors, including remote sensing. Potential indicators should be examined against the need to minimise cost and maximise efficiency; they should be assessed against the likely cost of populating them over 5, 10 and 20 years and the availability of existing datasets and monitoring schemes.

5. Integrative indicators

Wherever possible, integrative indicators, which integrate information from a number of subsidiary indicators, should be used. However, they should only be adopted where they can be interpreted in terms of one key soil function (cultural heritage preservation).

4. Assessing the Relevance of Potential Indicators

In this section potential indicators of change in soil quality, including those proposed by Loveland and Thompson (2002), are assessed according to their relevance to cultural heritage preservation. Indirect indicators of change in pressure are considered in section 4.1, whilst section 4.2 introduces specific soil properties as direct and indirect indicators of processes of soil change. This approach allowed for quick rejection of less relevant indicators, before beginning a more detailed assessment.

4.1 Indicators of Change in Pressure on Soil Quality

These are indirect indicators of soil quality based on changes in pressure at a national level (Table 3). Placing threshold values on these is problematic because a degree of land-use change in a necessary and inevitable process, which itself will become part of the cultural heritage record. Impact (frequency and magnitude) has been subjectively assessed; in any one instance impact will vary according to the resource, environmental conditions and mitigation methods employed.

Table 3: Pressures on cultural heritage preservation and their potential indicators

Pressures and threats		Resource affected	Impact		Potential indicators
			Frequency	Magnitude	
Land use change		A, L	**	**	Change in area of land use types
Agriculture	Arable	A, L	***	**	<u>Change in depth of ploughing</u> <i>Change in total area of ploughed land</i> <i>Area converted from grassland to cereal cultivation</i> Newly ploughed areas – including energy crops and forestry Intensity of manuring/fertilisation
	Grazing	A, L	***	*	Stocking levels <i>Area converted from cereal production to grassland</i>
	Forestry	A, L	**	**	<i>Area of forest / woodland</i> Area of new forestry planting
Mineral Extraction		A, L	*	***	Volume of material removed annually to mineral workings Area of land lost to mineral workings – including peat cutting Peat depth Number of archaeological ‘finds’ reported from mineral extraction works
Development		A, L	**	**	Rate of redevelopment within urban and rural areas Area of land lost to soil sealing
Recreation		A, L	**	*	Visitor numbers to specified landscapes and monuments New visitor facilities

underlined Loveland indicator for Heritage / archaeology, *italics* other Loveland indicator

* rare / small, ** occasional/moderate, *** frequent / large

A archaeology, L landscape

no highlight – rejected as irrelevant or not interpretable, **a** relevant, **a** highly relevant

4.1.1 Land use change

- Change in area of land use types

Changes in land use are typically driven by social, economic and political shifts and can present a major threat to cultural heritage preservation as they may bring about changes in landscape character and land management practices. Data on the extent of different land use types is readily available. However, the effect of many these different land uses on cultural heritage preservation is not well known and data on the extent of land use can mask areas where the pattern of land use is changing but total area is not. It also provides little direct information about the damage caused. For example are of cultivated land or forestry, does not provide information about the prevalence of potentially damaging operations such as deep ploughing, nor does it recognise the cultural resource element of areas of 'traditional' agriculture or ancient woodland. Hence, changes in area of land use it is not considered relevant as a stand alone indicator of cultural heritage preservation. Changing land use patterns (regionally and nationally) however, may be important in interpreting and making policy changes based on other indicators.

4.1.2 Arable agriculture

Change in depth of ploughing

- Change in total area of ploughed land
- Newly ploughed areas
- Area converted from grassland to cereal cultivation
- Intensity of manuring/fertilisation

Cultivation has been identified in the previous section as a major pressure affecting the cultural heritage resource. Hence, Loveland et al (2002) proposed change in total area of ploughing and change in depth of ploughing as headline indicators.

Plough depth, in combination with soil depth and the depth of archaeological remains, is a key variable as deeper ploughing allows damage to previously preserved stratigraphy. However, gradual surface lowering through compaction and soil erosion can also allow ploughs to bite deeper without any change to cultivation practice. Plough types and annual land management cycles are also important but at a national level the data does not exist to pursue such a farm specific approach.

Area of ploughed land is felt to be less useful as it takes no account of depth of ploughing, or of the previous history of the land being brought into cultivation. Environmentally Sensitive Area schemes, for example, can create temporary setasides that are subsequently brought back into cultivation. In this case, without a change in cultivation practice much damage has already been done and the indicator is not relevant. Likewise, for area converted from grassland (or forestry) to cereal cultivation.

Area of 'new' land brought into cultivation may be a better indicator. 'New' refers to land that been newly ploughed since 1939. In this way the archaeological value of historic and prehistoric field systems and cultivated soils is acknowledged.

Intensity of manuring/fertilisation is a key factor in determining cultural landscape character and landscape diversity (Frances Thin, pers. comm.). Addition of fertilisers and manure to previously nutrient poor areas can dramatically alter landscape character. Because the response of a soil to manuring is affected by initial loadings and soil conditions a more specific measure of soil fertility would be more meaningful.

4.1.3 Grazing

- Area converted from cereal to grassland
- Stocking level

There is a perception that cultural heritage in grazed areas is less threatened than in arable areas. In many instances this is true, for example Down Farm, Devon (Charles French, pers. comm.), however, deep rooting, reseeding, liming, and over-stocking can result in extensive damage, and grazing is the dominant land use in many areas. Measures of *area of land converted from cereal to grassland* are inappropriate given the already degraded soil resource. *Stocking levels* may provide an indication of increasing pressure in pastoral areas particularly in combination with livestock type and erosion risk. The difference between improved grassland and rough grassland in terms of the frequency of damaging operations must also be recognised. No single measure can be used to monitor actual damage to cultural heritage from changes in grassland area.

4.1.4 Forestry

- Area of forest/woodland
- Area of new forestry planting

Ploughing, harvesting, erosion, mechanical and rooting damage, and chemical changes to throughflow may affect archaeological and landscape preservation. As with changes to total area of ploughing, measures of the *area of forest/woodland* are insensitive to changing patterns of forestry in the landscape. Such data is however, held by the Forestry Commission and could be usefully incorporated with land use data in area of new cultivation and plough depth measures.

Area of new forestry planting takes some account of the historical depth to the soil and data on all areas of woodland over 2ha and areas of new planting are available from the forestry commission. Modern forestry practices may help to mitigate against damage to known archaeological remains, but not enough is known about the response of archaeological deposits beyond the area of planting to make interpretations based on this indicator. Including ploughing for forestry within the total area of new ploughing would be a more efficient indicator.

4.1.5 Mineral Extraction

- Volume/depth and area of material removed annually
- Number of archaeological ‘finds’ reported from extraction works

One of the implications of mineral extraction (including peat cutting) is the wholesale removal of soils together with the archaeological remains they hold and the elements of cultural landscape value they support. The direct effects of peat and mineral extraction on the loss of cultural heritage can only be monitored by measuring the number of sites or finds being recorded during the process of mineral extraction, or by measuring the area and volume / depth of Holocene and Palaeolithic deposits that have been removed.

Number of archaeological finds pays little regard to the cultural importance of soils and other environmental evidence, and the effort being made to identify ‘finds’. For example, the potential for site discovery is low where peat milling is used. Hence, this indicator is not considered further as a standalone indicator.

Volume/depth of material removed provides a measure of the loss of sediments and soils of high archaeological potential, in particular peat deposits where depth of peat is an important factor in the physical and chemical preservation of archaeological and palaeoenvironmental remains. *Area of land lost* is also relevant to cultural landscapes as well as to the loss of archaeological and palaeoenvironmental remains buried within and beneath alluvium and other superficial deposits. Depth / volume and area measurements in combination with data on the number of archaeological finds this could be a useful measure of the rate of loss of cultural heritage resources. Because of difference in resource type this measure would need to be able to differentiate between peat and other superficial deposits.

Peat is an important cultural heritage resource for the artefacts and archaeological remains it contains, as a component of many upland, and also lowland, cultural landscapes, and as a record of natural and anthropogenically driven environmental change. Peat cutting, wind and water erosion and drying and shrinkage however lead to a reduction in *peat depth*. However, because peat depth is a function of multiple processes (cutting, erosion and shrinkage) which have both physical and chemical implications for cultural heritage preservation, interpreting the effects and drivers for changes in peat depth can be difficult. Therefore, whilst the importance of areas of peat for cultural heritage preservation is recognised in this report it is felt that the best approach may be to monitor changes in peat ‘condition’ due to cutting, and erosion and shrinkage separately within the proposed indicators for loss of superficial deposits and erosion.

4.1.6 Development

- Rate of redevelopment within urban and rural areas
- Area of land lost to soil sealing

Development will affect landscape character and it can also have direct and indirect effects on the survival and preservation of archaeological remains through physical disturbance (excavation and compaction), pollution, dewatering or waterlogging, and alteration of the chemical and biological burial environment.

Rate of redevelopment in urban and rural areas could be used to monitor pressure on this resource, but because it takes no account of possible mitigation measures built into these developments (see Davis et al, 2004), it is potentially difficult to interpret the results in terms of cultural heritage preservation.

Area of soil sealing is a measure of urban and rural development. Monitoring is possible using remote sensing techniques (Wood et al. 2004), but would not provide information on associated damaging operations such as piling, drainage, and excavation. There is also a lack of information to allow interpretation of the direct effects of soil sealing on soil conditions, hence this indicator is not considered further.

4.1.7 Recreation

- Visitor numbers to specified landscapes and monuments
- New visitor facilities

Cultural heritage tourism is one of the tangible social benefits from archaeological sites and cultural landscapes. However, potential impacts include development (roads and visitor facilities) and erosion. Measures of visitor numbers and new visitor facilities may give an indication of increasing pressure, but wouldn't measure the damage being done. An independent measure of erosion is a more relevant soil indicator.

4.2 Indicators of change in soil properties and processes

(summarised in Table 4)

4.2.1 Erosion

- Erosion (including tillage erosion and peat wastage)
- Number of landscapes with erosion features
- Erosion risk (soil organic matter, slope shape, aggregate stability, soil texture)
- Catchment level river sediment yield

Soil erosion may be directly damaging to buried archaeological remains. Progressive lowering of the ground surface also exposes previously preserved remains to plough damage, bioturbation, oxidation, the effects of surface contamination etc., as well as negatively affecting the landscape setting through the silting of lakes, the development of erosion features and the degradation of soil quality.

Processes of erosion include wind, water, mass movements, and tillage erosion. It is the combined effects of these on the pattern of sediment redistribution that is most relevant to cultural heritage preservation. A direct indicator of *Erosion* must be a priority for any successful monitoring scheme.

The Loveland indicator of *numbers of landscapes with erosion features* only considers medium to large-scale erosion events and doesn't monitor ground surface lowering or sediment deposition, and hence is less relevant. *Catchment-level sediment yield* could provide an estimate of total sediment loss at a national level. However, this indicator only measures water erosion, not wind, mass movement or tillage erosion, or sediment deposition within the catchment. Hence, this too is less relevant.

Erosion risk is influenced by soil properties such as organic carbon content, aggregate stability, soil texture, and slope shape. A modelling approach based on these properties could provide an indirect means of mapping erosion risk in order to target sampling and interpret sediment redistribution data, or where no direct measure can be identified, as an indirect indicator of erosion. However, to be relevant this would need to be measured alongside a direct measure of sediment redistribution and hence is not suitable as a headline indicator in its own right.

Table 4: Soil properties and processes affecting cultural heritage preservation and their potential indicators.

Soil Property/ Process	Resource	Impact		Potential indicators
		Frequency	Magnitude	
Erosion	A, L	**	***	<u>Erosion (including sediment redistribution) (d)</u> <i>Number of landscapes with erosion features (d)</i> Catchment level river sediment yield (d) Erosion risk (soil organic matter, slope shape, aggregate stability, soil texture) (i)
Change in water table/soil wetness	A, L	***	**	Average depth of water table (d) <u>Maximum / minimum height of water table (d)</u> Soil moisture deficit (d) Soil moisture content (d)
Change in oxidation / reduction	A	***	**	Bulk soil redox potential (d) Groundwater redox potential (d)
Change in organic matter content	A, L	**	**	Total soil organic matter content (d) Total soil carbon content (d)
Change in pH	A (L)	**	**	Soil pH (d) Groundwater pH (d)
Alteration in biological activity	A (L)	***	**	<i>Microbial biomass C / Soil organic C (d)</i> <i>Respiration quotient based on soil N-mineralisation potential (d)</i> Redox (i) Depth of bioturbation (d) Earthworm numbers (d) Earthworm species presence (d) Rabbit/mole/badger activity (d) Depth of rooting (d)
Change in soil conductivity	A	**	**	Soil conductivity (d) Base saturation (i)
Pollutant loadings	A (L)	**	**	Soil P (d) Total heavy metal soil concentrations (d) Total concentration of specified organic pollutants (d) Total loadings of specified fertilisers and pesticides (d)
Compaction	A	**	**	Bulk density (d) Soil structure (d) Soil porosity (d)

(d) direct indicators, (i) indirect indicators

underlined Loveland indicator for Heritage / archaeology; *italics* other Loveland indicator

* rare / slight impact, ** occasional / moderate impact, *** frequent / large impact

no highlight – rejected as not relevant or not interpretable, a moderately relevant, b highly relevant

4.2.2 Soil Wetness/Watertable depth

- Average height of water table
- Maximum and minimum height of water table
- Soil moisture deficit
- Soil moisture content

There are two aspects to monitoring soil water changes; the first is the depth of permanent waterlogging, and the second is the soil moisture content above the watertable.

Average watertable depth is an important variable in archaeological heritage preservation. The onset of anaerobic conditions is closely linked with waterlogging, hence organic material permanently below the watertable is less susceptible to decay than that in the permanently or seasonally oxidised soil zones. Watertable depth is an important indicator of soil quality, monitoring the dewatering of deposits through drainage, irrigation, climate change, crop changes, development and mineral extraction. Waterlogging may also occur above the groundwater level in perched watertables. *Minimum and maximum watertable levels* are also highly relevant as this may produce flushing of the intermittently waterlogged zone as well as repeated variations in redox conditions.

The soil water is essential for many biological, chemical and physical processes of degradation and therefore, is an important factor in the preservation of cultural remains. Many processes are inhibited by very wet or very dry soil conditions. Properties of soil water that are important are soil water potential, pH (see 4.2.5), conductivity and solute concentration (see 4.2.7).

Soil moisture content is potentially a useful variable for modelling resource response to other changes in soil quality, but is not a particularly useful indicator in its own right. *Soil moisture deficit* proposed by Loveland et al. (2002) is defined by plant growth conditions and hence is a less suitable than indicator than soil moisture content.

4.2.3 Oxidation/reduction potential

- Bulk soil redox potential
- Groundwater redox potential

The availability of oxygen in the soil is an important variable in the preservation of archaeological artefacts, organic matter and stratigraphy as anaerobic conditions inhibit microbial and worm activity. The oxidation potential (or conversely reduction potential) is measured as redox potential and is affected by isolation from the atmosphere, soil drainage/wetness (waterlogging produces anaerobic conditions), organic matter content and biological activity (particularly microbes and roots). Dewatering of deposits through drainage, irrigation, or mineral extraction is particularly damaging as previously anaerobic deposits are exposed to oxygen resulting in increased microbial attack of fragile organic remains. An indicator of changes in burial redox conditions will be a key priority for any monitoring scheme.

Bulk soil redox potential is more relevant to cultural heritage preservation as this takes into account microbial soil activity and organic matter content more directly than *groundwater redox potential*.

4.2.4 Soil Organic Matter

- Soil organic carbon

Organic matter can itself be an archaeological resource but, because it is so sensitive to decay, only in highly anaerobic or highly desiccating environments is organic matter well preserved. Soil organic matter content is also a factor in erosion, biological and microbial activity, and the development of anaerobic conditions. The soil organic matter content of topsoils, buried archaeological strata, and buried soil/sediment matrices, therefore, could potentially be a key indicator of soil quality for cultural heritage preservation because of its relevance to a suite of degradation processes. Recently published, though contentious, research has suggested large, generalised declines in soil organic matter in the upper 30 cm of arable soils across the UK (Bellamy et al. 2005).

4.2.5 Soil pH

- Bulk soil pH
- Groundwater pH

Soil pH is a key factor in the preservation of many material types, as a determinant of ecosystem functioning it also plays a key role in maintaining landscape character. Soil pH is also correlated with redox potential, drainage conditions, and biological functioning. Changes in pH in either direction from current levels are potentially of concern. The response of a soil to external forcing of pH (atmospheric deposition, liming etc.) differs according to the prevailing soil conditions. Recent research has shown the negative effect of acid rain deposition on buried archaeological artefacts (Nord et al. 2005) although a generalised increase in soil pH has been reported for the period between 1978 and 1998 in UK soils following successful measures to tackle acid rain (Countryside Survey, 2000).

Bulk soil pH is likely to be most relevant to monitoring cultural heritage preservation in the oxidised soil zone. *Groundwater pH* may also be used in waterlogged areas though for consistency bulk soil pH would be preferable.

4.2.6 Biological activity

- Microbial biomass C / Soil organic C
- Respiration quotient based on soil N-mineralisation potential
- Redox
- Depth of bioturbation
- Earthworm numbers
- Rabbit/mole/badger activity
- Depth of rooting

Soil biodiversity and biological activity in archaeological deposits will be affected by the nature of the substrate (soil or anthropogenic deposit), the physical and chemical conditions in the soil or burial environment, and, in the upper parts of the profile at least, by land use and management.

A number of potential indicators of microbial activity were proposed by Loveland and Thompson (2002). Evaluating different potential biological indicators is the remit of the ongoing SQID Soil Quality Indicators – Developing Biological Indicators project, Phases I (SP0529) and II (SP0534). Biological indicators of soil quality have also been

considered by the Indicators of Soil Resilience for Scotland and Northern Ireland (SNIFFER LQ06). They concluded that it was ‘not possible to choose a single meaningful biological indicator to give a measure of the quality of all soils in Scotland and Northern Ireland.’ (Litterick et al. 2005). They recommend microbial biomass carbon, and/or potentially mineralisable nitrogen as potential indicators.

Both are thought to reflect microbial metabolic activity and soil organic matter turnover. However, both methods are laboratory based and require field sampling. Measures of microbial activity are particularly sensitive to perturbations, hence these laboratory based measures are not going to reflect actual activity in the field, particularly of anaerobic, buried systems, though locally they may provide a means of measuring the risk of microbial degradation to organic archaeological deposits in response to changes in the burial environment - particularly water content and redox potential. The lack of information about the effects of microbial activity in soil on archaeological materials and deposits makes interpretation, particularly at a national level difficult, hence although potentially important, microbial activity isn’t considered further here because of the lack of background knowledge and methodological issues.

As well as microbial activity the effects of soil macrofauna (earthworms, rabbits, badgers, moles etc.) and roots are potentially of concern. The number and activity of rabbits, badgers, moles etc. is felt to be regional or locally specific for incorporation into a national-level monitoring scheme. Their numbers may reflect changes in agricultural management, and natural population cycles more closely than specific soil changes.

Earthworm populations are more susceptible to changes in soil properties (particularly pH, drainage, and redox potential) and bioturbation can cause significant physical disturbance of buried stratigraphies. As well as numbers, the species present are critical in determining the extent and nature of the degradation as different species live and feed at different levels within the soil (Canti, 2003). However, little research has been done to ascertain the effect of different species on archaeological remains and their response to land management and other rapidly changing soil properties. Hence, they are not considered further as indicators in their own right.

Rooting can also cause significant damage to buried archaeological resources hence changes in root depth and density could have a significant effect on cultural heritage preservation. Root depth is influenced by species, hence changes in land use could be an important factor, and by soil properties such as water table depth. The interplay of soil properties and species in root depth makes this a difficult indicator to interpret let alone measure. Direct measurement of soil properties such as compaction and watertable depth may be more appropriate.

4.2.7 Soil conductivity

- Soil conductivity
- Base saturation

The corrosiveness of the soil solution is principally determined by soil conductivity and soil pH (Pollard et al. 2004). Conductivity is an important factor in processes of metal corrosion (Pollard et al. 2004) and in the establishment of chemical equilibria between artefacts and the soil water solution. This may be a particular problem in coastal areas affected by brackish water intrusion (Crowther, pers. comm.). Changes in soil conductivity can result in accelerated degradation of certain artefacts that had previously been in or close to equilibria with prevailing soil conditions. As such it can only be interpreted in conjunction with information about soil moisture, redox, soil and soil water chemical composition, and the chemical composition of the cultural heritage resource, and though locally important is less relevant to a national level monitoring scheme.

4.2.8 Pollutant loadings

- Soil phosphate
- Concentration of specified organic pollutants
- Loadings of specified fertilisers and pesticides
- Heavy metal soil concentrations

Phosphate - The association of phosphate with cess, dung and ash makes it a good indicator of former human activity (Crowther, 1997). Relic concentrations of phosphate and other plant nutrients in soils in and around former occupation sites are also important at a landscape level as they result in the lush, green vegetation typical of abandoned field systems and dwellings. These signals, however, can be swamped by modern applications of organic and inorganic fertilisers. Phosphate could be used as a generalised measure of total soil ‘contamination’ with respect to anthropogenic soil signatures, but the soil specific nature of phosphorus retention would make interpretation very difficult. However, phosphate is also linked with soil fertility and could be used to monitor changes in soil fertility that are significant with respect to cultural landscapes.

Metals – Soil concentrations of metals have been used variously in archaeology as markers of historical and prehistoric pollution (Rawlins et al, 2006) and to aid interpretation of space use in and around archaeological sites (e.g. Entwistle et al, 2000). In particular Pb, Cu, Zn and As are typically enhanced by human activity (Wilson et al. 2005; Davidson et al. in press) These signals are effectively the legacy of past pollution event. Both past and modern pollution may come from either a point or aerial source. As well as the concentration of pollutants, their effect will depend on the drainage, pH, cation exchange capacity, and redox potential, which will affect their transport laterally and vertically through the soil. Heavy metal concentrations are difficult to interpret and are directly relevant only to a specific class of archaeological information. Hence, they are not considered further for a national-level monitoring scheme.

Organics – The study of biomolecules in soil (Bull et al, 1999) and as residues on artefacts (e.g. Oudemans et al, in press) is relatively new in archaeology, but these organic molecules are an important potential source of cultural information. Potentially they are susceptible to changes in oxidation state, biological and microbial activity and down profile percolation of organic residues. However, very little is known about the persistence of biomolecules in soil. Phosphate is closely linked to organic matter additions and the use of phosphate and soil organic matter content as a proxy may be the most useful means of monitoring this aspect of the archaeological record at this time.

Fertilisers and pesticides - Recent studies of metal detectorists finds have indicated a potential problem arising from fertiliser and pesticide application (Denison and Dobinson, 1995). This could be a potentially important factor in cultural heritage preservation judging by the reported increase in the degree of degradation over a period of only a decade or two. A subsequent pilot study into the effects of agrichemicals on buried iron and copper artefacts (Pollard et al. 2004), suggests that agrochemicals can accelerate the rate of corrosion. However, although potentially relevant, not enough is yet known about the effects of specific compounds on different archaeological materials, the persistence and movement of these compounds through the soil, or of the influence of other soil factors on corrosivity, to allow interpretation of direct measurements of fertiliser and pesticide application. Hence, more research is needed to establish critical loads.

Fertiliser application also has implications for cultural landscape preservation as the current patchwork of soils that has evolved from past land management practices can be lost through modern improvement schemes. However, a direct measure of soil fertility, such as percentage base saturation would be a better indicator of soil quality than a measure of fertiliser application.

4.2.9 Compaction

- Bulk density

A degree of soil compaction is inevitable and unavoidable following burial of archaeological deposits. However, soil compaction, particularly of the upper soil profile, may be exacerbated by development, recreation, cultivation techniques, and livestock trampling. The effect of soil compaction on buried archaeological artefacts and deposits may include physical disturbance (erosion, compression, breakage, and reorientation of artefacts) but it may also lead to chemical and biological changes as pore space and drainage is reduced and can accelerate erosion. Soil compaction, therefore is an important process affecting archaeological preservation and soil quality for landscape preservation. However, the effects of compaction may be highly localised, for example around feeding troughs and gates, and in established wheel ruts.

4.3 Potential headline indicators

Based on the above discussions of relevance and interpretability, many potential indicators have been discarded. Of the remaining indicators, those prioritised on the basis of relevance are:

- Sediment redistribution – changes in ground surface
- Redox potential
- Average watertable depth and fluctuations
- Soil pH
- Soil organic matter content
- Area of new ploughing
- Depth of ploughing
- Area and volume / depth of material lost to mineral extraction / peat cutting

Area of new ploughing, depth of ploughing, and area / volume of material lost to mineral extraction are highly relevant to cultural heritage preservation, but are specific to land use or resource type, and hence are given a slightly lower relevance rating in the next section.

Also still in consideration as indirect indicators of change or of moderate relevance are:

- Soil P
- Compaction / bulk density
- Soil moisture content

5. Testing proposed indicators

Each of the proposed headline indicators were then tested against the criteria of *Sensitivity*, *Practicability*, *Efficiency and Cost*, and *Integration*, as outlined in Chapter 3. Each indicator was scored against each of these criteria (including *Relevance*) on a scale of 1 (poor) to 3 (good); a X (fail) was awarded where indicators failed a particular criteria, however, failed indicators were still scored against other criteria.

The scores for Relevance and Sensitivity were both given a 3x bias, and Practicability a 2x bias. This gave a total maximum score of 30. A score of 20 or greater was used as the basis for recommending headline indicators. Those indicators that performed badly for practicability and cost using current technology have been highlighted with a * as important headline indicators that might become practicable in the future. These scores are summarised in Appendix 4.

5.1 Area of new cultivation (*Relevance: 2*)

Sensitivity 2

The sensitivity of this indicator is dependant on the frequency of repeat measurements and on the classes of land use included within ‘cultivation’. The concept of ‘new cultivation’ since 1939 ensures that areas of set aside and fallow are implicitly included in the total area. The damaging nature of cultivation, particularly for buried archaeological remains, means that an unquantifiable amount of damage is inevitable between measurements.

Practicability 1

Geographically referenced, total area of cultivation may be inferred from aerial photography and satellite imagery (Wood et al, 2004). The June Agricultural census also contains annual data on areas of tillage and arable land dating back to 1866. However, this data can only be geo-referenced at a regional level. The historical element in this indicator requires georeferencing on a field by field basis, linked with an assessment of historical land use. Regional Historic Landscape Assessments have been undertaken, though not yet completed, across England, Scotland and Wales. These could provide the historical basis necessary, but unfortunately the methods used have not been consistent and this seriously compromises the usefulness of the dataset. Threshold values are of little use for interpreting changes in the area of new cultivation as this is a one-way process of land taken into agriculture.

Efficiency and cost 1

The need to establish consistent historical base-line data and the requirement for annual measurements whether by analysis of remotely sensed data or by census returns makes this a potentially expensive exercise.

Integrative Indicators 2

Total area of cultivation and Area of new cultivation could be integrated with indicators of depth of ploughing and erosion / sediment redistribution to provide more detailed information for interpretation of these indicators and to aid the identification of areas of threat at a regional and site-specific level.

Summary

Total score= (3x2)+(3x2)+(2x1)+1+2= 17*

Methodologies	GIS based approach using satellite data linked with Historic Landscape Assessment
Existing data sets	Regional HLAs, June Agricultural Census, Forestry Commission GIS data on woodland areas and new planting
Data interpretation	One way process therefore threshold values of little value. Rate of intake of previously uncultivated land that is of interest, particularly if linked to areas of high cultural value / sensitivity.
Possible Integration with other indicators	Depth of ploughing and sediment redistribution for better prediction of erosion risk
Recommendations	Not practicable with current base-line data as a headline indicator. May be used at a regional level where area of total cultivation shows marked increase over period of monitoring.

5.2 Depth of ploughing (*Relevance: 2*)

Sensitivity 1

The potential for loss of archaeological information between measurements is high as a single deep cultivation operation can be extremely damaging to buried archaeological deposits and artefacts. The method of monitoring will also affect the sensitivity of this indicator for detecting change.

Practicability X

An annual greatest depth of ploughing, or other operation, measurement cannot be arrived at directly by remote sensing methods (Wood et al, 2004). The only means of monitoring this is through farm surveys, possibly linked to the June Agricultural Census. However, interpretation of plough depth data also requires data on the nature, frequency and depth of previous operations. No baseline data of this sort exists and would be extremely difficult to gather for a national-level scheme. Interpretation of plough depth also requires knowledge of changes in absolute ground level.

Efficiency and cost 1

The need to establish base-line data on cultivation depth and to record and analyse annual census returns makes this a potentially very expensive exercise.

Integrative Indicators 1

An indicator of cultivation depth could be combined with total area of cultivation and with models of surface lowering to aid identification of regional and local areas at risk.

Summary

Total Score=(3x2)+(3x1)+(2x0)+1+1=11*

Methodologies	Remote sensing of crop type Census of crop type / cultivation methods / plough depth
Existing data sets	June Agricultural census Soil survey - soil depths
Data Interpretation	Only usefully interpretable relative to post-1950 maximum plough depth and soil depth.
Recommendations	Unsuitable / impractical as a headline indicator because of the practicality of obtaining data, the lack of baseline data, and difficulties in interpreting data.

5.3 Area and volume/depth of superficial deposits lost to mineral extraction

(Relevance: 2)

Sensitivity 2

The measurement of area / volume of sediment lost annually to mineral extraction and peat extraction necessarily includes an unquantified loss of cultural and palaeoenvironmental information. However, as this process involves the complete removal of soils, no other monitoring scheme is feasible.

Practicability 2

No one data set currently exists to monitor the volume and area of deposit loss. However, remote sensing could be used to identify both the areal extent and the depth and therefore the volume of material removed by mineral extraction. This could be teamed with peatland surveys, catchment flood maps, soil survey and British Geological Survey data sets (including the GeoSure 'The Thickness of the Superficial Deposits' and DigMapGB-625 data sets) to identify extent and depth of superficial deposits and identify areas for monitoring. Area measurements would be relatively straightforward using optical methods but do not take into account denudation processes such as peat milling, nor the high archaeological and palaeoenvironmental potential of deep deposits. Depth / volume measurements could be made using satellite or airborne Interferometric Synthetic Aperture Radar (IfSAR) to measure changes in surface topography. Interpretation would require knowledge of the depth of the superficial deposits of interest; this data may be available from the BGS or from site based investigation. Area/volume measurements could then be linked with SMR entries for archaeological discoveries in the areas affected in order to get a national feel for the actual loss of monuments. Accompanying changes in watertable depth would also be important for interpreting changes in preservation of buried deposits.

Efficiency and cost 2

The extent of superficial deposits of archaeological interest could be extrapolated from BGS datasets on drift deposits (coverage for made ground is poor), The Environment Agency and SEPA dataset of floodplain/floodrisk extent, and the National Peatlands Resource Inventory. Remote sensing of a selected sub-set of these areas could be relatively cheap and easy using airborne and / or satellite data.

Integrative Indicators 2

An integrated map of UK superficial deposits would be important for identifying areas of high archaeological potential at a national and regional level and could form a basis for selecting monitoring sites. Changes in peat depth as a result of cutting would also be monitored which could be useful in combination with data on peat shrinkage (section 5.4 and watertable depth section 5.5) as a specific indicator of changes in peat depth and cultural resource preservation in peat.

Summary

Total Score=(3x2)+(3x2)+(2x2)+2+2=20

Methodologies	Remote sensing: optical and IfSAR
Existing data sets	BGS, EA and SEPA catchment flood risk maps, wetland and peatlands surveys
Interpretation	This is a one-way process so threshold values are of little use. Of interest / concern would be an increase in the rate of deposit loss.
Gaps in knowledge	Effect of mineral extraction on cultural and palaeo-environmental deposits at distance from the site of mineral extraction through dewatering, contamination etc.
Recommendations	Suitable as a headline indicator to monitor the loss of superficial material at a national level

5.4 Erosion (including tillage erosion and peat wastage) (Relevance: 3)

Sensitivity 3

Estimates of surface lowering under arable cultivation are up to 3.9 mm/year on cropmark sites (Wilkinson et al. in press), and peat wastage can produce between 2 and 3.8 m surface lowering over 100 year period (French and Pryor, 1993; Hutchinson, 1980). Over time this can have a significant effect, particularly in combination with ploughing and other cultivation processes. Over a period of 10 years observable changes should be in the order of a few centimetres for arable cultivation or tens of centimetres for peat wastage.

Practicability 1

Direct small scale field measures of erosion and deposition are difficult to scale up to the landscape scale necessary for a national level monitoring scheme (Burke pers. comm.). Cs¹³⁷ has been used successfully to map patterns of soil erosion and deposition at the field scale (Walling et al, 2005; Wilkinson et al, in press). Airborne Cs¹³⁷ monitoring has not yet been tried but may be possible. However, the scale of mapping and the costs involved are likely to be too high for a national level monitoring scheme (Tyler pers. comm.). Changes in peat depth have traditionally been monitored by reference to fixed poles, however, data based on a single pole is very localised and many points would be required to extrapolate with any certainty. Peat depth has also been measured using geophysical techniques (GPR and electro-magnetic techniques), however, these are labour intensive and most suitable for site or regional level studies.

Wood et al. (2004) suggest that optical imaging in combination with digital terrain models may be suitable for assessing erosion based on the identification of erosion features. However, this provides only a very limited assessment of erosion processes and does not model surface lowering or upbuilding. Radar based measurements (Lidar and IfSAR) using airborne or satellite imagery have proved highly successful at creating relative topographic maps with a vertical accuracy of a few centimetres. However, monitoring change in surface elevation requires high resolution absolute topographic mapping. Currently these techniques are not sensitive enough to detect absolute changes with a resolution of a few centimetres as would be required for this monitoring project (Tyler, pers comm.). Developments and improvements to Lidar and IfSAR may make this feasible in the future.

With current capabilities, direct national-level monitoring of erosion and deposition would be extremely expensive. However, with a tiered approach, airborne radar or interferometry SAR could be used at site or landscape level where particular erosion risks had been identified by risk-based modelling using surface topography, soil organic matter, bulk density, soil type and land use changes. Such an approach has been used by Oxford Archaeology (2002) in relation to arable areas, and by Lilly et al, (2001). Existing erosion surveys in the UK have been site or landscape specific. Whilst these can be useful in interpreting change with respect to particular soil types and land use (particularly arable), they are not suitable for extrapolation as a base-line data set against which to measure acceleration or deceleration of erosion. Over the timescales involved and without previous national level data trends to assess acceleration (or deceleration) of erosion will only be possible through the use of comparative, 'semi-natural' reference sites.

Efficiency and cost 1

Erosion risk modelling could be carried out at a national level relatively cheaply using existing soil property data sets. However, to be able to interpret this at a national level also requires direct monitoring of sediment redistribution patterns. Current technologies are likely to be sensitive to do this only at a site by site level. Airborne and satellite mounted systems may be able to detect peat shrinkage and wastage, but are unlikely to be able to pick up the effects of tillage erosion for example. The technological limitations make populating a national data set extremely expensive at the current time.

Integrative indicators 3

Sediment redistribution indicators could be combined with cultivation area data, and local plough depth statistics to provide a powerful indicator of risk to archaeological remains. In combination with soil organic matter measures, risk based modelling could also detect changes in erosion risk with implications for both archaeological and cultural landscape preservation. For changes in peat depth as a result of erosion and shrinkage there is also a tie-in here with the previous indicator (sections 5.3). Changes in ground surface level would also be important data in the interpretation of changes in watertable depth and fluctuation (section 5.5).

Summary

Total Score=(3x3)+(3x3)+(2x1)+1+3=24*

Methodologies	Field based measurements Isotope measurements Lidar and IfSAR Erosion risk modelling
Data sets available	Site-specific and regional level erosion studies. Erosion risk models.
Interpretation	Surface lowering in combination with soil depth.
Integration potential	Plough depth, Water table depth.
Recommendations	A potentially important headline indicator of soil quality for cultural heritage preservation. However, practicable, cost effective methodologies are currently unavailable for anything above the site-specific level identified on the basis of regional or national risk based modelling. Should be made a priority for future national monitoring schemes.

5.5 Watertable level and fluctuations (*Relevance: 3*)

Sensitivity 1

Fluctuations in watertable level are principally controlled by precipitation, whilst ground level changes and vegetation change also influence mean watertable height and fluctuations in depth. However, because of the climatically controlled background variability, only large scale changes are likely to be detectable over the relatively short time-periods involved in this monitoring scheme. Dewatering can rapidly result in the complete destruction of sensitive organic materials, depending on burial depth and soil conditions, hence the possibility of severe unrecorded loss of information during the course of monitoring.

Practicability 2

Watertable depth and fluctuations may be inferred from the *soil morphology* (colour and intensity of mottling). However, such measures are insensitive because it is difficult to compare between soils, and because relict features reflecting previous water table levels may be preserved in the soil.

Dipwells fitted with divers are one of the commonest ways of monitoring watertable fluctuations. These permanent structures need to be installed in areas of low disturbance and must be sufficiently deep to contain free water throughout the monitoring period.

Baseline data collected over a 30 year period are necessary to identify climate controlled variability. Change should then be monitored relative to this. In general stable water tables are desirable and falling or increasingly variable water table depths are potentially detrimental.

Efficiency and cost 1

No national level monitoring scheme exists, though a few small regional studies could be made use of including that of the Forestry Commission. Because of temporal variability daily measurements are desirable. The main costs would be in installing dipwells and divers and in subsequent data analysis.

Integrative indicators 3

Watertable depth and fluctuations provide a good integrative indicator of soil quality for all aspects of cultural heritage preservation as it influences plant growth, soil fertility, redox potential, soil moisture, biological and microbiological activity, conductivity, and pollution diffusion. A range of divers are also available that measure groundwater temperature, conductivity, pH and dissolved oxygen concentration, which could be used at a site specific level.

Summary

Total Score=(3x3)+(3x2)+(2x1)+1+3=21*

Methodologies	GIS water accumulating / shedding sites Dipwells and divers
Existing data sets	No national level data sets and very little regional or site-specific baseline data covering 30 year historical monitoring period.
Interpretation	Climatically sensitive, therefore, requires long term data to pick out trends. Change in depth should be measured relative to current water table levels and in relation to water accumulating and water shedding sites.
Integration potential	Areas of mineral extraction to identify wider effects in terms of dewatering, Redox potential, microbial activity.
Recommendations	A highly relevant and important potential indicator. However, impractical over shorter timescales because of lack of good baseline data and high background variability.

5.6 Redox potential (Relevance 3)

Sensitivity 1

In general, it is assumed that a reducing environment is favourable for archaeological preservation. However, Hopkins (2004) warns that a low redox potential can mask degradation processes as anaerobes can operate in reducing environments and oxygen could still be reaching the deposit where it is rapidly utilised by aerobes. Patterns of redox potential are highly spatially variable even at the microscopic level. This is also a rapidly adjusting variable affected by watertable level and soil drainage, physical disturbance, and biological activity. Spatial and temporal variability creates a noisy background signal. In combination with diffusion of oxygen, this noisy background creates the potential for ‘masked’ degradation.

Practicability 1

Measurement of redox potential can be problematical as any disturbance of deposits can result in oxygen penetration; in-situ measurements are preferable to sampling. The redox

conditions of a soil can be estimated from the soil morphology, but this is an insensitive measure as relict features of previous oxidation states can be preserved in soil.

In-situ redox probes can be installed in soil profiles to measure soil characteristics, however, this involves excavation which is undesirable in areas of high archaeological potential and they provide localised measurements of this spatially and temporally variable property.

Deep dipwells with sampling or divers could be used to measure dissolved oxygen concentrations in groundwater. Dissolved oxygen concentration does not equate directly with redox potential, but it could be useful as a proxy measurement at a national or regional scale. However, dipwells cannot measure directly conditions in soil above the ground watertable or in perched watertables.

Redox measurements should be interpreted alongside watertable fluctuations, soil pH and soil organic matter content in order to model the likely response of the cultural heritage resource to changes in soil quality.

Efficiency and cost 1

The cost of installing and maintaining in-situ redox probes at a sufficient sampling points and sampling depths would be extremely expensive. If a national system of dipwells for watertable monitoring were established divers monitoring dissolved oxygen levels in groundwater could be installed for national level monitoring, though these are considerably more expensive than standard divers.

Integrative indicators 3

Redox potential can be integrated with soil pH and watertable level monitoring for maximum information and can be used to model changes in biological and microbiological activity, and groundwater and soil water corrosivity. However, at a national level, watertable monitoring may be sufficient to identify areas of concern.

Summary

Total Score=(3x3)+(3x1)+(2x1)+1+3=18*

Methodologies	In-situ field probes – Site disturbance and costly Field taphonomy – Insensitive to change Dissolved oxygen sensors in dipwells – Expensive and not directly interpretable in terms of redox potential.
Existing datasets	Site specific studies only
Interpretation	A move to oxidising conditions is damaging for many classes of archaeological material.
Potential integration	Watertable level, Area / volume of superficial deposits removed by mineral extraction, soil moisture content, microbiological activity.

Recommendations	Not currently practicable as a headline indicator, and methodological improvements seem unlikely in short to medium term for national level scheme, but is potentially of high importance. Watertable depth may be a more practicable option for monitoring.
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5.7 Soil Organic Carbon (*Relevance: 2*)

Sensitivity 2

Losses of soil organic carbon from the upper 15 cm of all soils in England and Wales have been estimated at 4.44 Tg/yr (Bellamy et al, 2005) over a 25 year period. Over the period of this monitoring scheme, therefore, changes of this order should be readily detectable, though it is not clear what impact changes of this magnitude are likely to have on buried archaeological resources and cultural landscapes.

Practicability 2

Organic carbon has been monitored in UK soils through the NSI, RSSS etc. However, each of these only samples the upper 15 cm of the soil (Bradley et al. 2003; Archer et al, 2003). Organic matter within the topsoil is relevant to cultural heritage preservation in terms of erosion risk and general health and resilience of the soil. Direct monitoring of organic archaeological deposits, however, would involve sampling repeated depths through archaeological profiles. Such repeat sampling would be very hard to replicate and hence would be meaningless, particularly as once oxygen was let in by previous sampling, microbial decay could affect buried soil carbon. Survival of organic archaeological deposits, therefore, could not easily be inferred from soil organic matter concentrations. Watertable levels and redox potential would provide a better means of modelling the survival of organic artefacts and deposits.

Because of the generality of soil organic matter content as an indicator of soil quality absolute threshold values are inappropriate. For example regarding erosion an increase in organic matter content is desirable. However, an increase may also encourage potentially detrimental biological processes. Changes in soil organic matter, either increase or decrease should therefore be seen in terms of changes in risk that may warrant further investigation at a regional level. Reference soil samples will be needed to interpret the results and to distinguish between climate change and land use/management effects and more work will be required to determine what levels of change should be considered significant.

Efficiency and cost 3

Baseline data is available for the whole of the UK in the soil carbon and land use database (Bradley et al, 2005). Based on the National soil inventory resample, recent trends in soil organic matter content have already been identified. Methods of sampling and analysis, therefore, should be chosen to ensure compatibility with these existing schemes.

Integrative Indicators 3

Soil organic matter in mineral soils is important in maintaining aggregate stability hence resistance to erosion (erodibility), soil structural properties hence drainage characteristics, and cation exchange capacity hence soil nutrient status. As such soil organic matter content is a good general indicator of soil quality for cultural heritage preservation providing an integrated indicator of resource health.

Summary

Total cost=(3x2)+(3x2)+(2x2)+3+3=22

Methodologies	Total soil organic carbon content
Existing data sets	UK Soil carbon and land use database
Interpretation	Changes in organic matter content can be interpreted in terms of erosion potential, redox potential, and microbial activity. Of relevance are changes from current levels. An increase in organic matter can be seen as beneficial in terms of erosion resistance and moisture holding characteristics. However, increases in microbial activity and bioturbation may have a negative impact and therefore, there are some difficulties in interpretation. Requires base-line data and reference profiles for interpretation.
Integration Potential	Erosion and sediment redistribution, microbiological activity, redox potential.
Recommendations	Potentially suitable as a headline indicator in its own right as a general, integrated measure of soil and cultural resource health

5.8 Soil pH (*Relevance: 2*)

Sensitivity 2

Soil pH is a property varying over short to longer time scales, linked to soil moisture content and land management practices. Hence, background variability is potentially high compared to any directional changes we might expect. Overall soil pH has been found to be increasing slightly across England and Wales (Haines-Young et al, 2000; Bellamy et al, 2004). However, these 20 year trends are slight and over a shorter period of time may be difficult to distinguish from background variability.

Practicability 2

For the purposes of monitoring buried deposits and in order to assess the effects of drainage and oxidation more fully on buried archaeological resources profile measurements will need to be made. Again a system of sampling 'natural' reference profiles may help distinguish between changes due to climate change and those due to land use/management regimes. Data will need to be interpreted alongside information on the nature of the cultural resource, land use, local geology and soil type, hence absolute thresholds may be inappropriate and further work will be required to determine the best

way to interpret changes in pH. The analytical methodology should be chosen to fit in with that used in existing data sets such as that of the National Soil Inventory.

Efficiency and cost 3

Soil pH has been included in existing monitoring and survey schemes including the National Soil Inventory, Representative Soil Sampling Scheme, Countryside Survey and Environmental Change Network. Hence, background data, including trends covering more than 20 years is readily available for the UK. Bellamy et al. (2004) found that spatial trends in soil pH change were weak and hence a design-based sampling scheme was suitable for monitoring purposes, hence some overlap with existing repeat monitoring sites, e.g. Countryside Survey, may be possible.

Integrative indicators 2

Soil pH is a factor in soil and soil water corrosivity to archaeological artefacts, it also affects biological activity, the retention of nutrients such as P in the soil and the mobility and diffusion of many pollutants. Hence, with careful interpretation soil pH could provide a general indicator of soil health for archaeological preservation.

Summary

Total cost=(3x2)+(3x2)+(2x2)+3+2=21

Methodologies	Soil pH
Existing data sets	NSI and NSI resurvey data, Soil survey data
Interpretation	Change from current soil pH, requires baseline data and reference soil profiles to monitor and interpret change. More research is needed to understand the effects of changing pH in the field on a range of archaeological materials.
Recommendations	Suitable as a headline indicator of soil quality for cultural heritage preservation, although more information may be needed to identify suitable thresholds of change.

5.9 Soil moisture content (Relevance: 2)

Sensitivity X

Soil moisture content is highly dependant on meteorological variables (precipitation, temperature, and humidity), vegetation type, and soil properties (texture, structure, and organic matter content). Hence, background variability both temporally and spatially is very high and only substantial changes will be detectable over a 10-20 year timescale.

Practicability 1

Because of the inherent spatial and temporal variability sample size for periodic sampling or in-situ monitoring programmes needs to be high. In-situ field monitoring is possible but interpretation of data from discrete data points could be unreliable. Interpretation would rely on knowledge of the gravimetric water content, hydraulic conductivity and local weather conditions and land cover. Remotely sensed data would be the preferable

option, but there are major difficulties associated with different land cover types, and field data is still required for calibration.

Satellite SAR backscatter data is linked to moisture but is also affected by vegetation, topography, and surface roughness. SAR data would, therefore, need to be combined with optical data for interpretation purposes, an approach that has had mixed success. At a national level problems associated with differences in ground cover and soil type are going to be large.

Efficiency and cost 2

Remotely sensed data is readily available and relatively cheap. However, interpretation would require skilled analysis of repeat data measures in combination with field samples, optical data and weather and climate data.

Integrative indicators 3

Soil water is the medium for a range of physical, chemical and biological processes that are potentially detrimental to cultural heritage preservation (both archaeological remains and cultural landscapes). Hence, if moisture was less variable it would be a general indicator of change in soil quality for cultural heritage preservation.

Summary

$$\text{Total Score}=(3 \times 2)+(3 \times 0)+(2 \times 1)+2+3=13$$

Methodologies	Gravimetric content, hydraulic conductivity, SAR remote sensing
Existing data sets	Unknown
Interpretation	Soil moisture is rapidly changing and variable in response to local weather conditions and land cover. Interpretation would require modelling of effects of soil moisture on other soil properties and processes.
Recommendations	Not suitable as a headline indicator

5.10 Phosphate (*Relevance: 2*)

Sensitivity 1

Phosphate is relatively immobile in soils and hence is a good potential indicator. However, rates of change in phosphate concentrations in archaeological soils are likely to be very slow given the often highly elevated concentrations and high inherent spatial and temporal variability (Crowther, pers comm.). The sensitivity of phosphate as an indicator for national level soil change, therefore, will be poor. The results may also be difficult to interpret given the soil specific nature of phosphate adsorption. Soil fertility is a function of a host of soil properties including structure and drainage, organic matter content, and other nutrient concentrations. Phosphate measurements alone, therefore, may not reveal significant changes in soil fertility.

Practicability 2

Phosphate concentration cannot be predicted from remote sensing, though overall soil fertility could be inferred from vegetation. Soil sampling and laboratory analysis would be required. As soil contamination has been ruled out because of sensitivity issues, soil fertility monitoring would only need to be carried out on the topsoil for a national level scheme.

There is no one agreed method for measuring archaeological phosphate concentration. Total P and bioavailable techniques have been used but are probably less relevant to archaeological studies. Olsen P may be the most suitable measure for calcareous and neutral soils, but is not suitable for acid soils, whilst Mehlich extractions are not suitable for calcareous soils. Crowther (1997) found that soil specific adsorption of phosphate is a particular problem for archaeological comparability, and would be an issue in any national-level monitoring scheme.

Efficiency and cost 2

Current data sets could provide baseline, but would involve costly repeat field sampling and lab analysis. Data should be interpreted in conjunction with the British Survey of Fertiliser Practice.

Integrative indicators 2

Phosphate analysis has two potential uses as a soil quality indicator for cultural heritage preservation. The first is as a proxy for modern soil contamination by organic wastes and the detrimental effect this may have on geoarchaeological information. However, the sensitivity of phosphate concentrations for this purpose is likely to be low. The second is as a measure of soil fertility linked to past agricultural activity, which is important in supporting the agricultural and semi-natural landscapes that exist today. Fertility could be assessed from soil P in combination with soil pH and soil organic matter.

Summary

Total score=(3x2)+(3x1)+(2x2)+2+1= 17

Methodologies	Total P, Organic P, Olsen P, Mehlich P etc.
Existing data sets	NSI survey data and resample. British Survey of Fertiliser Practice
Interpretation	Interpretation in terms of soil contamination and geoarchaeological potential would be extremely difficult. Interpretation in terms of changing soil fertility status may be possible by monitoring change from current levels with respect to reference soil profiles. More research is needed, however, to interpret this in terms of likely impact on the cultural landscape.
Recommendations	Not currently practicable as a headline indicator, but future research into changing soil fertility (including soil P) and its effect on cultural landscapes would be useful.

5.11 Compaction/bulk density (*Relevance: 2*)

Sensitivity 1

Soil compaction can result from inappropriate land management practices. However, seasonal changes resulting from drainage and freeze-thaw and management practices can temporarily affect soil structure and compaction. These seasonal changes could make it difficult to identify localised, longer term trends. As most compaction occurs with the first wheeling the potential for unidentified damage is high.

Practicability 2

Bulk density can be monitored in the field using cone penetrometers or neutron/gamma surface gauges to measure surface compaction. However, because of the inherent spatial and temporal variability a very large number of sample sites and repeat measurements would be required. Data would need to be interpreted in terms of land use and management, soil type and texture, and soil drainage conditions. Soil structure and compaction features could be used at a site specific level as indicators of compaction, but are not suitable as headline indicators.

Efficiency and cost 2

Because of spatial and temporal variability the number of monitoring sites would need to be high with repeat field visits, laboratory measurements and expert data analysis. If in future, digital elevation models were sensitive enough to pick up absolute changes in ground level of less than 10 cm, the potential would be there for monitoring sediment redistribution and compaction effects together at a national or regional level.

Integrative indicators 2

Changes in bulk density, together with soil organic carbon, could be used in developing erosion risk models.

Summary

$$\text{Total Score}=(3 \times 2)+(3 \times 1)+(2 \times 2)+2+2=17$$

Methodologies	Many different methods of measuring bulk density. Penetrometers may be used to measure surface compaction. For profile measurements test pits are necessary
Existing data sets	No UK wide data sets
Interpretation	Bulk density is highly variable spatially and temporally. Interpretation therefore is difficult and will require base-line data gathered over a period of time and reference profiles for comparison.
Recommendations	Bulk density is not suitable as a headline indicator because of spatial and temporal variability, the lack of baseline data and the myriad of different methods used. May be suitable at site-level where compaction is identified as a problem or where compaction is implicated in erosion.

6. Recommendations

6.1 Recommended headline indicators

A number of indicators scored 20 or more as potential headline indicators. However, of these a number were found to be impracticable at the current time because of lack of suitable technologies, background data, and studies into the response of cultural resources to changes in this soil property.

6.1.1 Currently practicable

The following indicators are those identified as both relevant and currently practicable with only small further investment to ascertain the most appropriate methodologies for analysis and interpretation, and to compile the necessary background data.

- Soil pH
- Soil organic carbon content

Hence these three measures are recommended as potential headline indicators of cultural heritage preservation. It is envisaged that soil, geological, climate and land use change data will be needed for national and regional interpretation of soil indicators, particularly soil chemistry indicators. The analytical methodology for soil pH and soil organic carbon should be chosen in accordance with those used in the development of existing data sets (such as the National Soil Inventory) to ensure comparability.

Methodologies for monitoring the loss of deposits (area and depth) to extraction also exist hence only moderate investment would be needed to develop a headline indicator.

- Area and volume/depth of superficial deposits lost annually to mineral extraction and peat cutting (including peat depth)

6.1.2 Currently impractical at national level

However, a number of highly relevant indicators were found to be impractical based on current technologies, knowledge of the resources response and / or the availability of suitable baseline data. It should be noted that some of these indicators scored below 20 because of cost and practicability. These include:

- Erosion and sediment redistribution
- Watertable depth and fluctuations, and / or soil redox potential
- Plough depth
- Area of new cultivation

Plough depth and area of new cultivation are also included here because although they are only relevant to areas under cultivation (hence a relevance score of 2) the potential damage to buried archaeological resources is known to be significant.

Because of their potential importance to the preservation of cultural heritage it is recommended that these areas should be a high priority for further research with the aim of developing indicators in the near future.

6.2 Gaps in our knowledge

Other areas where gaps in our current knowledge were identified include:

- Landscape level responses to changes in soil fertility, drainage, chemical and biological properties,
- Effects of fertilisers and pesticides on buried artefacts,
- Threats to archaeological monuments in areas of land-use other than arable,
- Responses of archaeological artefacts to change over time and the importance of pedogenic thresholds,
- The establishment of soil / artefact equilibria and the effects of perturbations of different scale.
- The effect of microbial activity on the decomposition of organic deposits and artefacts, and the response and consequences of changing soil conditions, particularly within buried deposits.

With the exception of soil organic carbon and pH, there is also a lack of suitable background soil data covering the whole of UK and a long enough time period to establish trends.

6.3 Potential regional and site-level indicators

Almost all of the indicators considered here are practicable at a site by site level for monitoring change where particular risks or threats have been identified. The most difficult process to monitor even on a site by site basis is probably redox because of the disturbance inherent in installing in-situ redox probes and the lack of absolute correlation between dissolved oxygen and localised redox potential. However, it is harder to identify those indicators that may be useful at the intermediate regional level. The possible potential for site and regional scale application of these indicators is outlined below:

- Erosion/sediment redistribution – Regional and site
- Redox potential – Site
- Watertable depth and fluctuations - Regional and site
- Compaction and bulk density - Site
- Heavy metal concentrations – Site
- Soil moisture - Regional
- Microbial activity – Site
- Phosphate concentration – Regional and site
- Plough depth – Site
- Plough area – Regional
- Soil organic carbon – Regional
- Soil and ground water conductivity – Regional and site
- Area/volume of superficial deposits removed – Regional
- Peat depth – Regional and site

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Appendix 1: Individuals contacted during consultations for stages 1, 3 and 4 of the project.

Organisation	Contact	Project stage		
		1	3	4
English Heritage	Sebastian Payne	*✓	*✓	*✓
English Heritage	Matt Canti	*✓	*✓	*✓
English Heritage	Steve Trow	*✓	*	
Historic Scotland	Andrew Burke	*✓		*✓
CADW	Astrid Caseldine	*✓		*✓
CADW	Matthew Ritchie	*✓		*✓
EHSNI	Terence Reeves-Smyth	*	*✓	
RDS, DEFRA	Joy Ede	*✓		*
DEFRA	Andrew Holden			*✓
DEFRA	Judith Stewart			*✓
Council Protection of Rural England	Tom Oliver		*✓	
National Trust	Rob Jarman	*✓	*	
National Trust for Scotland	Robin Turner	*	*	
Macaulay Institute	Allan Lilly	*✓		
Council for British Archaeology	Terry O'Connor		*	*✓
Countryside Agency	Colin Pritchard	*✓	*✓	
Environment Agency	Graham Merrington	*✓		
Environment Agency	Jane Morris	*✓		
Scottish Natural Heritage	Patricia Bruneau	*✓	*✓	*✓
Scottish Natural Heritage	Frances Thin	*✓	*✓	
Forestry Commission	Peter Crow	*✓	*	*✓
Forestry Commission	Andy Moffat			*✓
Countryside Council for Wales	Dylan Williams			*✓
University of Cambridge	Charly French		*✓	
University of Wales, Lampeter	John Crowther	*✓	*✓	

✓ responded

Appendix 2: Pressures, threats, responses and potential impacts on the cultural heritage resource

Major Pressures	Component threats	Potential soil responses	Potential impact of land use and soil changes
Agriculture	<p>Cultivation – Ploughing, Trafficking of farm machinery, Fertiliser, liming and pesticide applications, Cropping, Baring of soil surface, Stone/boulder clearance, Removal of field boundaries, Farm buildings</p>	<p>Plough damage Erosion/tillage erosion Addition of fertilisers and pesticides Decrease soil organic matter Decrease in aggregate stability Increase in bulk density Change in soil structure Additional organic and inorganic pollutant loadings Changes in soil pH, phosphate, and base saturation Change in soil biota</p>	<p><i>Archaeology</i> Physical destruction: plough damage and erosion Physical alteration – compaction, aggregate breakdown and fine matter translocation. Chemical loadings: organic and inorganic pollutants may alter past loadings Chemical and biological weathering of artefacts: changes in pH, redox, soil wetness conditions, corrosive agri-chemicals Organic matter decomposition: changes in redox and soil microbiology <i>Landscape</i> Landscape character: loss of hedges, changes in field sizes Monument loss/damage: erosion Erosion scars and silting of lakes and waterways: accelerated erosion</p>
	<p>Drainage - Lowering of watertable, Fluctuating watertable Trenching</p>	<p>More oxidising soil conditions Change in seasonal redox conditions Change in soil pH Increased/renewed organic decomposition Change in soil biology</p>	<p><i>Archaeology</i> Chemical and biological weathering of artefacts: changes in pH, oxidising, drier soil conditions. Organic matter decomposition: changes in redox and soil microbiology. Physical disruption and homogenisation – increased activity of soil macro-fauna. <i>Landscape</i> Habitat support: change in nature of habitat that can be supported. Peat wastage and shrinkage.</p>
	<p>Grazing – Trampling and poaching, Fertiliser and lime applications Reseeding,</p>	<p>Increased erosion Increased compaction Change in soil structure Plough damage Addition of fertilisers</p>	<p><i>Archaeology</i> Physical removal: erosion Physical alteration: compaction Chemical loadings: organic and inorganic pollutants may alter past loadings Chemical and biological weathering of artefacts: changes in pH, redox, soil wetness conditions, corrosive agri-chemicals <i>Landscape</i> Landscape character: change in field systems and built heritage.</p>
	<p>Forestry – Ploughing, Tree growth, Fertiliser, Cropping, Forestry roads and infrastructure</p>	<p>Increased rooting (depth and quantity) Ploughing of new areas Lowering of water table level Change in soil pH Change in soil macro-fauna and microbiology</p>	<p><i>Archaeology</i> Physical destruction: plough and erosion Physical alteration: root penetration Chemical and biological weathering: dewatering, pH, redox and rhizosphere and microbiological changes. Organic matter decomposition: dewatering and redox. <i>Landscape</i> Physical change in landscape character in newly planted areas and loss of ancient woodland. Monument loss/damage: erosion. Erosion scars and silting of waterways and lakes: accelerated erosion.</p>

Appendix 2 continued

Major Pressures	Component threats	Potential soil responses	Potential impact of land use and soil changes
Development	Brownfield redevelopment Urban spread Roads and other infrastructure Energy generation	Increased bulk density Change in soil structure Earth-moving Alteration of water table level and fluctuations Change in redox conditions Change in soil water quality Loadings of pollutants Soil sealing	<i>Archaeology</i> Physical destruction: earth-moving resulting in loss or truncation of deposits Physical alteration: compaction Chemical loadings: organic and inorganic pollutants Chemical and biological weathering: changes in watertable level, pH, and redox Organic matter decomposition: if water tables fall. <i>Landscape</i> Change in landscape character: urbanisation Loss of monuments: earth moving
Mineral extraction	Mining Quarrying River gravel extraction Peat cutting Turf cutting	Lowering of water table and changes in fluctuations More oxidising soil conditions Change in soil water quality Earth moving/removal Loadings of pollutants	<i>Archaeology</i> Physical removal – peat or overburden containing cultural deposits Physical alteration – Compaction below spoil and tips, bioturbation associated with lower water table. Chemical loadings: Inorganic pollutants in soil and ground water and soil. Chemical and biological weathering: changes in water table and redox Organic matter decomposition: associated with falling water tables and oxidising soil conditions <i>Landscape</i> Physical loss of certain habitats and landscape features Physical alteration: earth-moving
Industry	Atmospheric deposition Processing site Effluent /waste disposal	Loadings of pollutants (organic and inorganic) Soil sealing Increased compaction Earth moving/removal	<i>Archaeology</i> Physical removal: earthmoving, compaction Chemical loadings: organic and inorganic pollutants in soil and groundwater Chemical weathering: changes in pH, base saturation and conductivity <i>Landscape</i> Change in cultural landscape character
Waste Management	Waste disposal Waste processing Effluent	Loadings of pollutants (organic and inorganic) Increased compaction Earth moving/removal Atmospheric deposition	<i>Archaeology</i> Chemical loadings: organic and inorganic pollutants Physical alteration: compaction damage, loss and truncation of deposits. <i>Landscape</i> Change in landscape character

Appendix 2 continued

Major Pressures	Component threats	Potential soil responses	Potential impact of land use and soil changes
Tourism/leisure	Footpaths Visitor facilities	Erosion Increased soil compaction Soil sealing	<i>Archaeology</i> Physical degradation of monuments: erosion, compaction <i>Landscape</i> Erosive scars in valued landscapes Change in landscape character
Climate change	Change in precipitation and temperature patterns, Sea-level change	Change in watertable level and fluctuations Change in soil redox conditions Erosion Increased soil temperatures Renewed or altered pedogenic processes	<i>Archaeology</i> Physical loss: increased erosion, including coastal erosion Physical disruption: lowering of water table and increased bioturbation Soil process changes: changes in soil water regime Chemical and biological weathering: Change in soil wetness, pH and redox Organic matter decomposition: changes in redox, soil temperature and soil biology <i>Landscape</i> Loss of ability to support certain habitats Increased erosion and silting of waterways and lakes

Appendix 3: Threats to archaeological preservation

Agriculture and forestry

The Monuments at Risk Survey (Darvill and Fulton, 1998) highlighted agriculture as one of the major factors in the destruction and degradation of the archaeological resource, in particular arable cultivation. Arable agriculture is a threat to both mineral soils and organic wetland soils.

Physical damage can result directly from ploughing, harvesting, and compaction and indirectly through increased erosion. Drainage, irrigation, liming, fertiliser and pesticide addition, and reductions in soil organic matter through cropping also affect the physical, chemical and biological burial environment (Oxford Archaeology, 2002). For example dewatering can lead to shrinkage and oxidation of organic remains (Van de Noort et al. 2002), and fertiliser and pesticide application has been shown to adversely affect the preservation of metallic objects (Dobinson and Dennison, 1995; Pollard et al, 2004)

Pastoral activity may also affect archaeological remains through drainage, reseeded, liming, fertiliser application and mechanical damage caused by overstocking. However, these effects are much less well studied and recent government initiatives to reduce stocking levels may be helping to mitigate against these pressures (Trow, pers. comm.).

Changes in land use and land management are potentially very damaging as they represent a further disturbance in near-equilibria between archaeological materials and the soil. Hence, set aside of arable land brings its own threats, for example from deep rooting and changes in evapo-transpiration, and occasional land management practices such as sub-soiling and deep ploughing are especially damaging (Oxford Archaeology, 2002). Potential conversion of land to biofuel production over the next few decades may also affect soil quality (Department for Transport, 2004, Towards a UK Strategy for Biofuels – Public Consultation).

Development

Many urban town centres contain a particularly rich and complex archaeological resource. As many of these developed in river valleys the potential for ecofacts and good organic preservation are also high. Urban redevelopment and brown field decontamination (McCaffrey et al. 2005), as well as new rural and urban fringe development, can be a threat to physical archaeological remains as well as destroying the geochemical soil record of previous phases of human activity. The effects of soil sealing on archaeological potential are not well researched, but as well as direct effects of construction such as compaction, soil sealing could affect ground water levels through recharge and the soils redox potential with consequences for the biological functioning of the soil. Urbanisation of the environment also has a direct influence on landscape character. Energy generation projects are also of concern and are included here under development.

Mineral extraction

Locally peat, mineral and aggregate extraction can have a devastating effect on the cultural record. The Monuments At Risk Survey (Darvill and Fulton, 1998) survey found that between 1945 and 1995, 12% of all observed destructions of archaeological sites were as a result of mineral extraction. Although the total land area affected by extraction

is small, for example 0.5% of England's current wetlands, this tends to be focussed on particular environments for example the loss of more than half of England's lowland peats (Van de Noort et al, 2002).

Mineral extraction and peat cutting results in the wholesale removal of sites and ecofacts. Deep alluvial valley bottoms, gravels and peat are particularly sensitive as waterlogging and rapid accumulation means they have the potential to contain well preserved organic remains and stratigraphies. However, mitigation can be difficult as the extent and location of this resource is generally unknown. As well as wholesale removal of sites, mineral extraction can also result in localised compaction as well as dewatering and pollution over a larger area well away from the extraction area.

Climate change

Climate change "threatens to impact upon all aspects of daily life, not least the survival of heritage assets" (English Heritage, 2004 – Heritage Counts). Predicted climate changes for the UK over the next 80 years (Hulme et al, 2002) could be a driver for renewed or altered pedogenesis, whilst changes in precipitation and evapotranspiration patterns could affect soil erosion and water table levels with potentially devastating effects for wetland and waterlogged archaeological deposits. Climate change may also act as a driver for changes in land use, for example the increased cultivation of biofuel crops, and land use management practices such as irrigation with indirect consequences for cultural heritage preservation.

Appendix 4: Summary table of potential indicators and criteria scores.

Potential indicator	Criteria testing					Score	Recommendation
	Relevance (x3)	Sensitivity (x3)	Practicability (x2)	Cost	Integration		
Area of new ploughing	2 (6)	2 (6)	1 (2)	1	2	17*	Currently impractical
Depth of ploughing	2 (6)	1 (3)	X	1	1	11*	Currently impractical
Area/volume of superficial deposits lost to mineral extraction	2 (6)	2 (6)	2 (4)	2	2	20	Headline indicator
Erosion (including tillage erosion and peat wastage)	3 (9)	3 (9)	1 (2)	1	3	24*	Currently impractical
Watertable depth and fluctuations	3 (9)	1 (3)	2 (4)	1	3	21*	Currently impractical
Soil redox potential	3 (9)	1 (3)	1 (2)	1	3	18*	Currently impractical
Soil organic carbon	2 (6)	2 (6)	2 (4)	3	3	22	Headline indicator
Soil pH	2 (6)	2 (6)	2 (4)	3	2	21	Headline indicator
Soil moisture content	2 (6)	X	1 (3)	2	3	13	Rejected
Soil phosphate content	2 (6)	1 (3)	2 (4)	2	2	17	Rejected
Compaction / bulk density	2 (6)	1 (3)	2 (4)	2	2	17	Rejected