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SID 5 Research Project Final Report

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### Project identification

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<tr>
<td>1.</td>
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Executive Summary

Context
Soils are an inherent feature of the natural landscape, and an important component of land as a natural resource. As such, soils in England and Wales provide a range of services that support a broad spectrum of human activities and associated benefits. However, much evidence suggests that the way soils are used results in their degradation, giving rise to significant costs, not only to immediate users of soils but also society as a whole, now and into the future. The Defra’s Soil Strategy for England, for example, put the total cost of soil degradation at about £206-£315 million per year, but recognised that this was probably an underestimate.

Objectives and approach
This study aimed to estimate the total economic cost of soil degradation in England and Wales in order to inform priority areas for future research and policy. Six main processes of soil degradation and their effects on soil quality were indentified for analysis, namely: erosion, compaction, decline in organic content, loss of soil biota, diffuse contamination and surface sealing. An ecosystem services framework was used to assess how degradation affects the capacity of soils to support provisioning services such as food and fibre production, regulating services associated with water quality, flood control and climate, and cultural services associated with landscapes, recreation and habitats. Emphasis was placed on the generation of ‘final goods’ that are of value to people, distinguishing between onsite and offsite costs, and market and non market effects.

A review of literature, expert judgement, soils data inventories held by the National Soils Resources Institute, land use data from the Countryside Survey, other secondary sources and modelled calculations were used to produce estimates of degradation costs for dominant ‘soilscapes’ in England and Wales, that is combinations of land cover and soil type.

Results
The Table below shows that soil degradation costs that can be quantified in money terms range between £0.9 bn and £1.4 bn per year, with a central estimate of £1.2 bn. About 45% of total quantified annual soil degradation costs are associated with loss of organic content of soils, 39% with compaction and 13% with erosion. 20% of the estimated annual costs of soil degradation are associated with loss of provisioning services linked with agricultural production, both reduced output and increased costs. The remaining 80% of total annual degradation costs are associated with loss of regulating services, the bulk of this (49% of all costs) linked to GHG emissions. Flood related costs (flood damage and flood risk management) account for about 19% of total costs and water quality related costs (both drinking water and freshwater water) account for about 11% of quantified costs. 80% of costs occur offsite and as such are of limited concern to those who actions may be responsible for soil degradation. Over 70% of erosion and compaction costs are linked to arable farming, whereas almost 60% of loss of organic content is linked to grassland, especially on peat soils. This distribution of costs indicates the priority areas for future policy.

Summary of estimated total quantified costs of soil degradation in England and Wales classified by ecosystem services and impact category
This assessment confirms the difficulty, experienced by previous assessments, of deriving complete and reliable estimates of the benefits provided by soils and how these change according to soil condition. Three main areas of uncertainty arise, namely (i) ‘identifying’ biophysical relationships between soil properties, soil functions and ‘performance’ of soils in particular applications, (ii) ‘valuing’ the diverse range of market and non market benefits and costs attributable to soils in different applications and (iii) assessing the ‘dynamics’ of changes in soil properties as these affect changes in the value of services, especially under conditions of climate change. An understanding of the role of soils in support of cultural services is particularly lacking, especially associated with nature conservation.

From a policy perspective, set in the context of the EU’s Thematic Strategy for Soil Protection Strategy and UK national soil strategies, there is an economic argument to focus on the avoidance of soil compaction and erosion on intensively farmed soils and the maintenance of organic content of soils generally. Indeed, protecting the carbon content of soils would probably embrace all aspects of soil quality and associated benefits. In an urban context, the avoidance of flood risk associated with soil sealing should be a focus.

The ecosystems service perspective employed here requires that soil science and management adopt a broader remit to include the wide range of soil functions and related benefits, strengthening the links between soil science research and policy and practice for this purpose.
1. Introduction

1.1 Context

Soils are an inherent feature of the natural landscape and an important component of land as a natural resource. As such, soils in England and Wales provide a range of services that support a broad spectrum of human activities and associated benefits. The relationship between people and the natural environment has received much attention recently. The UK National Ecosystem Assessment\(^1\) confirms the importance of natural capital to enhancing human welfare through a wide range of highly valued ecosystem services. The recent White Paper for England - The Natural Choice\(^2\) articulates a commitment to protecting and improving the natural environment, justified to a great extent on the added social and economic value of doing so. Indeed, specific reference is made to improving the management of soils, especially in the context of climate change.

The contribution of soil to welfare is also clearly articulated in the recent Soil Strategy for England\(^3\). It argues that the continued provision of benefits from soil depends on the maintaining their physical, chemical, and biological properties. However, much evidence suggests that the way soils are used results in the degradation of soil quality and the functions that soils support. This can result in significant costs, not only to immediate users of soils but also society as a whole, now and into the future.

One of the reasons why degradation occurs is that many costs arising from soil degradation are not borne by those who make decisions about land use and management. Many impacts are felt ‘off-site’ in the form of non market ‘external’ costs borne by third parties without compensation - a clear case of market and institutional failure. Examples include the flooding of property caused by rapid runoff of water from cultivated hillslopes and the climate change impacts of carbon released from farmed peatlands. Having a more comprehensive valuation of degradation costs, and ensuring these are in some way accounted for in land management decisions, could lead to different outcomes. In some cases, soil degradation has arisen as a result of policy interventions by government such as the promotion of some types of intensive agriculture. There is now much greater awareness of such risks and the need to guard against them.

According to European Commission’s Thematic Strategy for Soil Protection\(^4\), degradation processes that threaten soil resources include: i) soil erosion, ii) organic matter decline, iii) compaction, iv) salinisation, v) landslides, vi) contamination vii) soil sealing, and viii) loss of soil biodiversity. These, with the exception of salinisation and landslides, are identified sources of degradation in Defra’s Soil Strategy for England\(^5\). The Strategy estimated the total cost of soil degradation at about £206 million - £315 million per year, comprising the costs of soil erosion (including onsite damage to crops) (£45 million/year), loss of soil carbon (£82 million/year), flood damage due to run off from degraded soils (£29-£128 million), and sediment removal in urban drainage systems (£50-60million/year). The assessment recognized that this was an incomplete estimate. These costs are incurred in many different ways, affecting a diverse range of ecosystems services and benefits to people, over a range of spatial and temporal scales, making estimation particularly challenging.

1.2 Objectives and Approach

The overall aim of the project is to produce an estimate of the total economic cost of soil degradation in England and Wales, in order to support future policy on soils, informing priority areas accordingly. The specific objectives are to address six broad questions, as follows:

Objective 1: What is soil degradation, its causes and its effects on soil properties?

This objective is addressed by identifying and defining the characteristics of soil degradation that occurs through deterioration of physical, biological and chemical properties. It focuses on erosion by wind and water, compaction, decline in organic content, loss of biotic matter, diffuse contamination and surface sealing.

Objective 2: What are the links between changes in soil properties due to degradation, soil related ecosystem services, and benefits and costs society?

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\(^1\) UK NEA (2011). UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, Cambridge


\(^5\) Defra (2009) as cited above
This is addressed by constructing and applying a framework that links degradation processes and changes in soil quality to ecosystem services, distinguishing between provisioning, regulating and cultural services, and selecting appropriate methods for the classification and valuation of costs.

**Objective 3: What is the actual occurrence or probability of soil degradation in England and Wales?**
This is addressed by identifying the actual or potential probability of soil degradation in England and Wales which provides the basis for changes in soil services and subsequently, along with economic values, estimates of damage costs. This involves a review of existing literature, reports, and databases, drawing on our own expertise in soil science and the tools and data we have available through the National Soil Resources Institute. We classify the probability of degradation processes by types of ‘soilscape’, that is major combinations of land use and soil type, and the way these are spatially distributed.

**Objective 4: What data are available and what methods can be used to determine the economic costs of soil degradation for dominant soil type and landuse situations?**
This is addressed by identifying and applying the relevant economic data, both market and non-market, to value the change in service provision by soils, and hence in the value of ‘final goods’, resulting from soil degradation. We use selected cases to provide real world insights.

**Objective 5: What are the total economic costs of soil degradation in England and Wales?**
This involves deriving estimates of the aggregate costs of soil degradation, classified by typologies of land uses, landscapes, soils and ecosystems. This allows for the spatial pattern of different types, extents and costs of soil degradation. The total costs of degradation and the likely extra costs or benefits of more or less soil degradation are assessed, in order for inform policy priorities.

**Objective 6: What are the main uncertainties in the estimates and gaps in the knowledge**
This involves review of major sources of uncertainties, gaps in knowledge and recommendations on how these might be addressed.

Figure 1 summarises the approach adopted here. The effects of soil degradation on the quality of soils and the ‘supporting services’ provided by soils are identified and assessed in the context of broad soilscape. From this, likely changes in the main ecosystem services are assessed and, as far as possible, changes in the monetary value of ‘final’ goods and services that impact on the welfare of people.

![Diagram of soil degradation processes and ecosystem services](image)

**Figure 1 The approach to the assessment of the cost of soil degradation**

This summary report is support by a number of appendices that provide details of methods and results.
2 Soil Degradation: Processes, Causes and Effects on Soil Properties

The Thematic Strategy for Soil Protection\(^6\) identifies eight degradation processes that threaten soil resources, of which erosion, compaction, loss of organic matter, loss of soil biodiversity, diffuse contamination and surface sealing are the principal means by which soils are degraded in England and Wales. Soil degradation is caused by the deterioration of physical, biological and chemical soil properties driven by natural and anthropogenic pressures\(^7\). These are summarised as follows:

**Erosion**: the detachment, entrainment, transport and deposition of soil particles or small soil aggregates, by an erosive force such as water, wind, tillage and co-extraction with root vegetables and machinery. Propensity to erosion is dependent on the force of the erosive agent (erosivity; e.g. mass and velocity of a raindrop or velocity of water or wind flow) and susceptibility to erosive force (e.g. soil aggregate stability, soil texture, availability of fine particles/aggregates, shear strength, soil moisture, ground cover and slope gradient and length). Physical changes include loss of top soil, preferential removal of finer particles, surface sealing and breakdown of soil structure. Biological changes include loss of organic matter and loss of biodiversity. Chemically, erosion can increase pH, reduce available nutrients such as P and N and affect base saturation.

**Compaction**: the physical reduction in volume of soil due to a compressive force. Compaction occurs as a result of soil vulnerability or applied stress to the soil (either separately or in combination). Physically, compaction causes a reduction in pore space with a preferential loss of larger pore spaces. The reduced pore space impacts on both soil fauna and flora. It can also lead to an increased loss of greenhouse gases (e.g. nitrous oxide) and ammonia, and a reduction in carbon dioxide and methane.

**Loss of organic matter**: the reduction in organic material through oxidation, reduced accumulation or physical removal. This is as a consequence of increased oxidation, reduced moisture content and extraction. Physical effects include reduced water holding capacity and reduced nutrient retention. Loss of organic matter can lead to a decrease in biodiversity and reduce the chemical buffering capacity of the soil.

**Loss of soil biodiversity**: the reduction in the number of species, taxa, communities of living organisms present in the soil. Changes are caused by a loss of habitat, contamination by pollution and change in environmental conditions. The effects on physical properties include changes to soil structure and its stability and a reduction in soil formation. Biologically, loss of soil biodiversity can affect the resistance and resilience to soil perturbation. Chemically, it can impact on nutrient cycling, availability and loss.

**Diffuse contamination**: the contamination of the soil by atmospheric deposition, flood water and direct chemical input, caused by the addition of chemical pollutants or over-application of agricultural chemicals. The process can damage soil structure and impact on soil biodiversity and associated soil functions. It can also reduce the chemical buffering capacity of the soil and increase toxicity to other living organisms.

**Surface sealing**: the detachment of the soil from the biosphere and atmosphere. This can be temporary (e.g. caused by soil capping) or permanent (e.g. construction of infrastructure, housing etc). Physical effects include reduced ground permeability, compaction and reduced heat exchange. The process removes habitat for soil fauna and flora, and reduces carbon and nutrient cycling.

\(^6\) Commission of the European Communities. 2006. Thematic Strategy for Soil Protection

\(^7\) Appendix A describes the processes, causes and effects of degradation on soil properties for the six primary causes of soil degradation in England and Wales
3 Links between soil degradation and soil related ecosystem services

The impact of soil degradation on ecosystems goods and services can be classified into four main categories as defined by the Millennium Ecosystem Assessment\(^8\), relating to provisioning, regulating, cultural and supporting services (Table 1)\(^9\). These impacts are summarised below.

### Table 1 Generic approach to the classification and valuation of ecosystem services

<table>
<thead>
<tr>
<th>Ecosystem service</th>
<th>Examples of services</th>
<th>Benefits to people</th>
<th>Examples of valuation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Supporting</strong> other</td>
<td>Soil formation, Habitats, Biodiversity,</td>
<td>Through support to provisioning, regulating and cultural services</td>
<td>Not directly valued</td>
</tr>
<tr>
<td><strong>processes and services</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Provisioning</strong> of</td>
<td>Agricultural production, Forest products</td>
<td>Agricultural commodities, Minerals, Energy, Water use</td>
<td>Market prices of: agricultural commodities; farm land values</td>
</tr>
<tr>
<td>**material goods and</td>
<td>Mineral extraction, Water supplies,</td>
<td></td>
<td>net subsidies to farmers</td>
</tr>
<tr>
<td><strong>services</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Regulating</strong> of</td>
<td>Flood control, Erosion control, Carbon storage,</td>
<td>Flood damage avoidance, Social cost of carbon, Water quality, Waste management</td>
<td>Avoided urban flood damage/flood defence costs, Economic</td>
</tr>
<tr>
<td><strong>ecosystem processes</strong></td>
<td>Water purification</td>
<td></td>
<td>value of carbon storage, Water treatment costs</td>
</tr>
<tr>
<td><strong>Cultural, non material</strong></td>
<td>Heritage, Landscape, Amenity, Recreation, Social relations</td>
<td>Heritage sites, Landscape features, Countryside walks, Tourist visits</td>
<td>Willingness to pay for: habitat creation and maintenance,</td>
</tr>
<tr>
<td><strong>services</strong></td>
<td></td>
<td></td>
<td>heritage preservation, green-space, countryside recreation</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Costs of protection of habitats</td>
</tr>
</tbody>
</table>

### 3.1 Supporting services

Soils provide a range of ‘supporting’ services, such as the cycling of nutrients, and atmospheric gases as well as providing habitats for biodiversity, above and below the ground surface (see Figure 1 above). These support the functioning of ecosystems (usually classified by habitat type) and the range of services that they provide. The ability of soil to provide this support is dependent on its rate of formation and retention. Soil formation is a very slow process and therefore in human terms soil can be regarded as a non-renewable resource. Erosion and changes to soil biodiversity, as affected by diffuse contamination and surface sealing, curtail soil formation. The retention of soil is therefore critical and affected by soil erosion together with loss of organic matter and loss of soil biodiversity which affect soil cohesion and soil loss. While surface sealing enhances the retention of soil, it neutralises many positive functions.

Soil erosion reduces nutrient cycling by removing nutrients, dispersing nutrients and interrupting the nutrient cycle. Compaction can both increase and decrease nutrient cycles through changes in soil moisture and oxygen contents. Soil biodiversity affected by erosion, compaction and diffuse contamination can also affect nutrient cycling because of changes in community structure and function.

Water cycling is disrupted by soil erosion, compaction and surface sealing. Storage of water is restricted if the water cannot enter (infiltrate) or be held in the soil matrix. This limits plant available water and may necessitate artificial irrigation. Changes to water storage capacity will impinge of local stream flow regulation. At times of heavy rainfall, limited storage capacity will result in a rapid rise in river flow and may increase the risk of down stream flooding. However, at times of low rainfall, limited water storage capacity will curtail stream recharge and may affect the capacity to extract water for industry and domestic use.

Habitats are destroyed by soil erosion, compaction, diffuse contamination and surface sealing. Depth of soil restricts soil microbiological communities, while compaction restricts mobility of soil fauna and root growth. Loss of soil organic matter also reduces the size and diversity of soil microbiological communities because of a change in habitat and in particular a reduction in food and energy sources. In turn changes to soil biodiversity caused by changes in organic matter content can result in a negative feedback loop in which less organic matter is decomposed resulting in further soil community changes. Diffuse contamination affects habitat through changes in organic matter decomposition, with consequent effects on soil microbiological communities.

Soil erosion reduces primary production because of restricted rooting depth and restricted nutrient and water availability, affecting vegetation growth and limiting seed production and dispersal. Compaction can increase foot problems in animals and therefore restrict land use for animal husbandry. Surface sealing prevents all primary production.

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\(^9\) Appendix B details the impact on ecosystem goods and services caused by the six main soil degradation processes identified for England and Wales.
Diffuse contamination and surface sealing can impact on infrastructure. Contamination may restrict what the land can be designated for. Contaminants below sealed surfaces may affect the integrity of a structure through corrosion.

### 3.2 Provisioning services

Soil properties have a major influence on crop production. The availability of soil as growth media for a crop is probably the most important provisioning service. Soil erosion reduces the depth and volume of the available growth media. Surface sealing prevents the growth of plants due to lack of water infiltration and difficulty in seedling emergence through the seal. Diffuse contamination can restrict crop growth and type (e.g. because of concerns over human and animal health within the food chain). Apart from the loss of soil (productive) area, loss of biodiversity may also limit the speed at which soil can be formed. In addition to availability of soil, availability of nutrients also plays an important role in crop production. Soil erosion removes nutrients preferentially, while changes to microbiological soil communities as a result of compaction, diffuse contamination, surface sealing and a loss of biodiversity may affect nutrient cycling and nutrient availability to plants. Loss of organic matter can also reduce plant available nutrients. Other factors that affect crop production include abrasion caused by wind erosion. Abrasion damages seedlings, lowers the marketable value of a crop and increase the susceptibility of plants to diseases and insect attack. Crop production can also be affected by plant stress as a result of inundation by deposited materials, water stress caused by compaction and loss of organic matter, and phytotoxicity caused by diffuse contamination.

The provision of plant available water and both domestic and industrial supplies of water can be affected by soil degradation. Storage of water in the soil depends on available pore space. Therefore, compaction or removal of soil by erosion (including the loss of organic material) reduces the available water storage capacity. Factors that restrict infiltration also disrupt the provision of water. Infiltration can be restricted by surface compaction and surface sealing.

The deposition of sediment and nutrients in water courses can also impact water quality and increase the cost of providing potable water. This deposition can also harm commercial fisheries and block navigable channels hindering there use by commercial shipping.

The soil can also provide materials that can be used for medicines, pharmaceuticals and industrial materials. Loss of biodiversity will reduce the available pool of genetic material. Factors such as compaction and diffuse contamination that alter genetic diversity and surface sealing, which restricts access to the soil resource below it, will disrupt the provision of medicines and pharmaceuticals. Surface sealing will also restrict or prevent access to industrial materials below the sealed surface.

### 3.3 Regulating services

Soil erosion and loss of organic matter reduce carbon sequestration and increase loss of stored carbon via breakdown of organic matter. The emitted greenhouse gases (carbon dioxide, methane and nitrous oxide) will contribute to climate change. Carbon sequestration is also affected by surface sealing, which will preserve the carbon store below, but will also prevent further sequestration. Regulation of carbon flux may also be reduced by a loss of soil biodiversity.

Water quality is affected by the deposition of sediment and nutrients in water courses. A reduced buffering capacity of the soil, brought about through the processes of soil erosion, loss of organic matter, loss of soil biodiversity, diffuse contamination and surface sealing will have negative effects on water quality too. Loss of soil through erosion reduces the amount of interaction of chemicals with the soil. The loss of organic matter, loss of soil biodiversity and diffuse contamination affect the soils ability to adsorb or neutralise chemicals. This is due to reduced cation exchange capacity or loss of ability to transform chemicals. Compaction may also affect water quality by increasing the risk of soil erosion.

The ability of soil to store and release water slowly over time and facilitate recharge of ground water, aids the regulation of water provision. Infiltration is affected by soil structure, therefore, processes that lead to the deterioration of soil structure i.e. a loss of larger macropores, will affect infiltration. Compaction, loss of soil biodiversity, diffuse contamination by saline water and surface sealing also affect infiltration adversely. A reduction in infiltration causes an increase in overland flow and increases the risk of down stream flooding because of the reduced time between rainfall and peak flow. The ability of a soil to retain water once it has infiltrated is also related to soil structure, in particular pore size distribution. Soil erosion, compaction and loss of biodiversity reduce available pore space for water storage. Loss of organic matter also reduces a soils storage capacity. Surface sealing can either restrict or prevent infiltration of water into the soil and therefore soil that is sealed cannot contribute to soil water storage capacity or ground water recharge.

Air quality is affected by suspended dust particles initiated by wind erosion, exasperated by dry soil conditions that may be a consequence of loss of organic matter. Surface sealing protects the soil below it from erosive forces, however, a sealed surface is a faster drying surface on which dust can generate. Sealed surfaces can still contribute to the suspended dust particle load.

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Pest and diseases may be reduced by soil erosion and surface sealing because of reduced biological activity in the soil. However, loss of soil biodiversity has been linked with increased risk of human infectious diseases such as lyme disease, anthrax and hookworm (Patz et al., 2004).

### 3.4 Cultural services

People appreciate how the landscape looks i.e. its aesthetic value. Soil erosion can degrade the aesthetic look of the landscape, through the loss of a visual feature or the appearance of erosion features within the landscape. A landscape may be valued because of a particular land cover that may be affected by changes in soil biodiversity or even totally lost through surface sealing.

Wellbeing may be affected by how soil degradation impacts on our health. Wind erosion and diffuse contamination impact on human and animal health, for example causing pollution that can antagonise underlying ailments such as asthma, or poisoning fodder and food crops. Health may also be put at risk from the deposition of eroded material on roads increasing the risk of vehicle accidents. Financial pressures can also affect the way we feel, for example repair cost to buildings and machinery damaged by soil erosion or crops lost to diffuse contamination. Wellbeing is also affected by the visual changes in a certain landscape. For example, surface sealing may reduce the level of positive or negative feeling we have about an area.

Soil degradation can also disrupt our day to day routines or way of life. A road blocked by sediment deposition can restrict or prevent access. Flooding caused by compaction or surface sealing can lead to temporary isolation of an area and may promote outward migration of people not willing to stay in a flood risk area or unable to afford insurance premiums. Diffuse contamination may enforce a change in land use and management that is unfamiliar, requiring new skills and maybe even a change in life style. Tourism can be an important revenue generator, in particular for rural area of England and Wales. Factors that affect aesthetic value, sense of well being and ability to undertake recreational pursuits e.g. fishing and boating, will reduce an area’s appeal to visitors.

The capacity of the land to provide recreational activities may be reduced by a loss of soil through erosion and surface sealing. Ironically the activities themselves may exacerbate the rate of erosion, for example commercial peat cutting to provide peat compost for recreational and commercial gardening supplies and use of footpaths in fragile upland ecosystems. Diffuse contamination may prevent or restrict access to areas of land formerly or with the potential to provide recreational activities.

Heritage can be affected through damage to buried artefacts, caused by soil erosion uncovering fragile remains; damage caused by either compaction of the soil or its remediation; and the process of surface sealing. Peat soils in particular, because of their properties, contain valuable records of past environments and cultural activities which can be lost through erosion or removal of the organic layer. Surface sealing may help to preserve buried artefacts because of the anaerobic conditions it creates. However, surface sealing may also change the historic land use of an area and prevent investigation of past cultural heritage. It is reported that connectivity with the soil is fundamental to human/nature interactions.
4 Framework for the Economic Assessment of Soil Degradation

Soils are an element of natural capital. Soil stocks, described in terms of their quantities and qualities, as well as their contextual attributes such as altitude, topography, climate, hydrology and location, have potential to provide a range of benefits to people in the form of ecosystem services. The use of soils in pursuit of benefit can, however lead to their degradation, resulting in loss of benefit or increased costs.

4.1 Soils Stock and Flows of Soils Services

Degradation of the soil resource refers to a decline over time in the value stock of soil assets and a reduction in the value of future services provided by them. The concept is similar to that of depreciation of a physical asset, evident in the reduction of its remaining value over time. Thus in Figure 1, the value of degradation is the change in the value of soil over an accounting period, equivalent to the depreciation of physical assets. Degradation, if continued and unabated, would eventually lead to complete loss of soil assets.

Figure 2 Graphical representation of the degradation of the value of stocks of soil

The stock:flow relationship can be expressed as a difference equation as follows:

\[ \Delta S_t = f(S_t, X_t, Z) \]

Where: \( S_t \) is the stock at a particular point in time \( t \) (for example taken to be a given year end) and delta \( S \) is the change in \( S \) during the time period \( t \), \( X_t = (X_{t1}, ..., X_{tn}) \) are external variables that are associated with change in the stock characteristics of soils such as land use and soil structure, and, \( Z = (Z_{1}, ..., Z_{m}) \) are the ‘state’ variables such as type of soil and topographical that do not change.

Usually \( f < 0 \), indicating that the degradation has a negative effect on the stock value.

Then:

\[ S_{t+1} = S_t + \Delta S_t \]

or

\[ S_{t+1} - S_t = f(S_t, X_t, Z) \]

If \( f \), the degradation function, is independent of \( S_t \) then the general case applies as follows

\[ S_T = S_0 + \sum_{t=0}^{T-1} f(X_t, Z) \]

The stock value at any point in time is a function of the initial stock value and the cumulative effects of degradation (or appreciation) over time. If, however, as often might be the case, there is an interaction between stock and the rate of degradation (either increasing or decreasing relative to stock value) then a more complex relationship applies.
From an economist’s perspective, the value of a stock at a point in time is determined by the present value of the future flows of services, discounted at the social discount rate\(^{10}\). Thus a change in the stock value is indicated by the change in the present value of flows of services rendered. For example: the reduction in carbon content of soils associated with emissions to atmosphere results in costs borne by society measured at the social cost of carbon. The present value sum of these emissions can indicate a decline in the value of soil carbon stocks between any two points in time. A similar approach can be used in principle for the value of soils as a medium for food production. It is noted however that some degraded services may be substituted by other ‘replacement’ inputs, such as artificial fertilisers. This does not reduce the loss of stock value. Rather it substitutes the natural functions of soil at an additional cost.

It is impossible, and unnecessary, to determine the value of soil stocks. It is possible, however, to determine the variations in the condition of stocks of soils (eg the degree of erosion, compaction, carbon content) and the likely implications for flows of services. This is the approach adopted here, using the ecosystems framework, by estimating the change in the value of annual service flows, that is the annual costs of the degradation of soil stocks.

### 4.2 The Counterfactual ‘Without Degradation’ Situation

It is required to define a baseline ‘counterfactual’ situation against which the economic costs of soil degradation can be ascertained. The counterfactual is the condition of soils, both in terms of stock and flow values, which would prevail in the absence of degradation, \((S_{t+1} = S_t\) above).

Given the predominantly managed soilscape of England and Wales, the counterfactual is set in the context of each dominant soilscape. Thus, the degradation that arises from the particular land use is identified together with the costs of degradation associated with that particular land use. As explained below, the analysis focuses on loss of value added and additional costs, whether associated with substitution of soil properties or mitigation to prevent their loss.

### 4.3 Classifying the Costs of Soil Degradation

An ecosystem services framework is adopted here to assess the economic costs of different processes of soil degradation. Many of the services provided by soils are intermediate supporting services that underpin provisioning, regulating and cultural services. Emphasis is placed on the generation of ‘final goods’ that are of value to people.

Consistent with other classification approaches, these final goods incorporate on-site and off-site effects, private and public benefits, as well as use and non use benefits (Table 2). Soil degradation results in a reduction in the quantity and quality of soil as a component of natural capital and hence a reduction in the quantity and quality of flows of ecosystem services. These changes in stocks and flows are expressed in economic terms where possible.

<table>
<thead>
<tr>
<th>Spatial extent</th>
<th>Type of cost</th>
<th>Ecosystems perspective</th>
<th>Economic perspective</th>
<th>Basis for valuation</th>
</tr>
</thead>
<tbody>
<tr>
<td>On site:</td>
<td>Productivity loss, Damage costs Mitigation costs</td>
<td>Mainly provisioning services eg agricultural production Cultural services to on-site users</td>
<td>Mainly ‘private’ costs borne by individuals and organisations Some non market costs borne by site users</td>
<td>Mainly market prices Non market prices for uncompensated site users</td>
</tr>
<tr>
<td>Offsite:</td>
<td>Damage costs Mitigation costs.</td>
<td>Mainly regulation eg flood control, GHG regulation and cultural services eg recreational, property values</td>
<td>Public costs borne by society at large</td>
<td>Combination of market and non market prices Non monetary (intangible) impacts</td>
</tr>
<tr>
<td>Total</td>
<td>Combined on- and off site Combined value of provisioning, regulating and cultural services</td>
<td>Combined value of private and public costs</td>
<td>Mix of market prices (adjusted for taxes and subsidies) and non market prices. Non monetary (intangible) impacts</td>
<td></td>
</tr>
</tbody>
</table>

Onsite costs accrue at the location of the degradation processes. They are mainly (but not exclusively) borne by those causing degradation and as such are mainly ‘private’ costs to individuals and organisations. Offsite costs accrue elsewhere and are borne by third parties, usually without compensation, and are therefore mainly public/societal costs. Some on-site costs may be public costs that accrue to users, such as walkers in the countryside, whose non market benefits are reduced without compensation (assuming they cannot go elsewhere to derive the same net benefit).

\(^{10}\) See HMT (2003), The Green Book. Her Majesty’s Treasury, London for a discussion on the choice of discount rates for public investment appraisal. High discount rates tend to encourage relatively rapid depletion of soils whereas low discount rates tend to encourage soil conservation strategies in order to secure continued future benefits from soils.
The majority of onsite private costs can be valued using market prices. The valuation of offsite, public costs may involve a mix of market and non market prices. It is noted, however, that onsite costs may include some non-market costs, such as the stress or loss of amenity or reputation caused by a degradation process, such as a serious soil erosion incident on farm land.

From an economic viewpoint the cost of soil degradation is the sum of onsite and offsite costs (with some adjustments to market prices to remove the effect of taxes and subsidies). Evidence to date suggests that offsite costs exceed onsite costs by a large margin, and that the onsite benefits of soil conservation may be less than the costs involved. This might not, however, be the case from the public perspective. Thus, much of soil policy is concerned with identifying total costs of soil degradation, and where appropriate, using cost effective policy measures to reduce degradation in the public interest. This may involve a mixture of regulatory, economic and voluntary instruments.

5 Estimating the Incidence of Soil Degradation in England and Wales

In order to evaluate the economic consequences (impacts and costs) of soil degradation, it is first necessary to identify the probability of degradation in terms of degree (intensity) and extent (spatial distribution). Subsequently, the probability of soil degradation can be combined with estimates of economic impact to determine the ‘risk of soil degradation’, that is:

\[ R = \sum_{i=1}^{n} (p_i \times c_i) \]

Where \( R \) is the total annual cost of soil degradation and \( p_i \) and \( c_i \) are the probability of and annual costs associated with a particular degradation process \( i \) respectively.

5.1 Soil degradation: a soilscape approach

The probability of different soil degradation processes was shown to be associated with two main factors: land cover and soil type, modified by ‘state’ parameters such as climate zone and topography. For this reason, an assessment was made of the likelihood of degradation processes for major ‘soilscapes’ in England and Wales\(^\text{11}\).

In order to simplify the process of estimating the economic costs of soil degradation, the national land area of England and Wales was divided into 40 landuse/soil type categories, referred to as ‘soilscapes’. The ten land use categories selected were: i) urban, ii) horticultural production, iii) intensive arable production, iv) extensive arable production, v) improved grassland, vi) unimproved grassland, vii) rough grassland, viii) forestry, ix) woodland and x) wildscape. The four soil types were: i) clay, ii) silt, iii) sand and, iv) peat. Both the landuse and soil type categories were judged to be sufficiently different from each other, as to make treating them separately worthwhile.

The land use categories were developed using LCM2000\(^\text{12}\) 25 m level 3 data, sampled at 1x1 km intervals. The land use at that sample point was assigned to the whole 1x1 km cell and then used to inform the new landuse assignation developed for this project. The NATMAP dataset\(^\text{13}\) was used to develop the soilscape layer. As much of the soil in England and Wales is classified as loam, this was allocated on the basis of textural dominance. The spatial interpretation of the LCM2000 data and the NATMAP data are shown in Figure 3.

These data were then intersected in a GIS to obtain the total area of land within each of the 40 soilscapes. For the purposes of calculation, the total sealed surface of the area, based on an analysis of GIS data\(^\text{14}\) quantifying the density of road surfaces and built up areas within each 1x1 km square, was removed from the total area estimated for the other land use. The resulting value of estimated agricultural arable and grassland land use for England and Wales from this analysis was 10,254,433 ha which is close to agricultural land use in England and Wales given by Defra for 2010 (10,416,700 ha as given in the Agriculture in the United Kingdom 2010 for England and Wales\(^\text{15}\)). Table 3 shows the areas of land use, soil type and soilscapes. 55% of land cover by area involves horticultural and arable farming. 59% of soils by area are predominantly clays.

A correlation of land cover and soils by multiple point observations reveals a statically significant relationship between the two factors. Table 4 shows the distribution of land cover by soil type, comparing actual incidence of land use with what might be expected based on the relative areas of soil types. Silts and sands are more than proportionately used for horticulture and intensive arable (including root crops and field vegetables). Peatlands are

\(^{11}\) The process is described in detail in Appendix D
\(^{13}\) NATMAP: http://www.landis.org.uk/data/natmap.cfm
\(^{14}\) Countryside Information System: http://www.eugris.info/displayresource.asp?Cat=maps,%20data,%20statistics,%20registers&resourceID=4995
more than proportionately committed to extensive grassland and wildscapes, particularly reflecting upland soilscape.

Table 3 Estimated areas of soilscape in England and Wales

<table>
<thead>
<tr>
<th>Land use</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
<th>Peat</th>
<th>% area by land use</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>887,200</td>
<td>147,900</td>
<td>416,500</td>
<td>20,600</td>
<td>11%</td>
</tr>
<tr>
<td>Horticulture</td>
<td>25,865</td>
<td>18,357</td>
<td>15,306</td>
<td>1,280</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Arable intensive</td>
<td>172,841</td>
<td>83,731</td>
<td>99,330</td>
<td>8,234</td>
<td>3%</td>
</tr>
<tr>
<td>Arable extensive</td>
<td>2,719,842</td>
<td>542,876</td>
<td>774,493</td>
<td>46,997</td>
<td>29%</td>
</tr>
<tr>
<td>Grassland improved</td>
<td>2,300,360</td>
<td>462,761</td>
<td>582,906</td>
<td>129,170</td>
<td>25%</td>
</tr>
<tr>
<td>Grassland unimproved</td>
<td>733,419</td>
<td>123,289</td>
<td>209,579</td>
<td>535,332</td>
<td>11%</td>
</tr>
<tr>
<td>Rough grassland</td>
<td>346,707</td>
<td>73,579</td>
<td>161,262</td>
<td>86,914</td>
<td>5%</td>
</tr>
<tr>
<td>Forestry</td>
<td>150,009</td>
<td>30,192</td>
<td>100,666</td>
<td>124,791</td>
<td>3%</td>
</tr>
<tr>
<td>Woodland</td>
<td>680,383</td>
<td>158,698</td>
<td>236,225</td>
<td>53,581</td>
<td>8%</td>
</tr>
<tr>
<td>Wildscape</td>
<td>152,700</td>
<td>39,200</td>
<td>90,900</td>
<td>384,600</td>
<td>5%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Land use</th>
<th>% by soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>59%</td>
</tr>
<tr>
<td>Horticulture</td>
<td>12%</td>
</tr>
<tr>
<td>Arable intensive</td>
<td>20%</td>
</tr>
<tr>
<td>Arable extensive</td>
<td>9%</td>
</tr>
<tr>
<td>Grassland improved</td>
<td>5%</td>
</tr>
<tr>
<td>Grassland unimproved</td>
<td>12%</td>
</tr>
<tr>
<td>Rough grassland</td>
<td>6%</td>
</tr>
<tr>
<td>Forestry</td>
<td>5%</td>
</tr>
<tr>
<td>Woodland</td>
<td>5%</td>
</tr>
<tr>
<td>Wildscape</td>
<td>5%</td>
</tr>
</tbody>
</table>

Table 4 Soilscapes and the distribution of land cover by dominant soil type in England and Wales

<table>
<thead>
<tr>
<th>Land use</th>
<th>Ratio of “actual” to “expected” soilscape areas: 100% implies actual equal expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clay</td>
<td>Silt</td>
</tr>
<tr>
<td>Urban</td>
<td>102%</td>
</tr>
<tr>
<td>Horticulture</td>
<td>73%</td>
</tr>
<tr>
<td>Arable intensive</td>
<td>81%</td>
</tr>
<tr>
<td>Arable extensive</td>
<td>113%</td>
</tr>
<tr>
<td>Grassland improved</td>
<td>112%</td>
</tr>
<tr>
<td>Grassland unimproved</td>
<td>80%</td>
</tr>
<tr>
<td>Rough grassland</td>
<td>89%</td>
</tr>
<tr>
<td>Forestry</td>
<td>63%</td>
</tr>
<tr>
<td>Woodland</td>
<td>102%</td>
</tr>
<tr>
<td>Wildscape</td>
<td>39%</td>
</tr>
</tbody>
</table>

Figure 3 Land cover based on LCM 2000 (on the left) and soil texture (type) based on NSRI data (on the right)

5.2 Development of an Agricultural Soilscape Model of England and Wales

Since much of the costs of soil degradation are associated with agriculture, which occupies the great majority of land in England and Wales, a production model was combined with the soilscape categories to determine the impact of different types of degradation on ecosystem service flows\(^\text{16}\).

\(^{16}\) see Appendix E
The proportion of crops in each landuse/soil type category was developed using the LCM2000\(^{17}\) data. The area of those categories that were “unknown” in the LCM2000\(^{18}\) sample, were distributed to the known categories in proportion to their occurrence. The distribution was then simplified, as appropriate, to a number of key crops that were modelled.

Crop yield data for these landuse/soil type categories\(^{19}\) were developed from equations in the Silsoe Whole Farm Model\(^{20}\) for sand, silt, and clay. Crops yields for peat were taken from Morris et al., 2010 and the annual per hectare yield of timber was developed from Forestry Commission for timber production in England and Wales and divided by the total area of forestry and woodland areas identified in LCM2000. The value for grassland was taken as the feed value of grass calculated in relation to the feed value of barley (\(£\) MJ\(^{-1}\)). The input data and economic value associated with the crops in the production model were developed from Regional Farm Business Survey results\(^{21}\)\(^{2}\) and other published sources\(^{23\ 24}\).

### 6. The current extent and intensity of soil degradation in England and Wales

Drawing on a combination of literature, expert judgement and analysis of NSRI data sets, an assessment was made of the probability of different degradation processes occurring in different soilscape\(^{25}\). These are summarised here\(^{26}\).

#### 6.1 Soil erosion

Soil erosion, which is estimated to affect 17 per cent of the land in England and Wales, is mainly confined to particular to soilscape, mostly on lighter arable soils on hillslopes and of peats in upland areas. Our understanding of erosion occurring in other soilscape is limited. Estimates of intensity of soil erosion beyond the individual plot scale tend to be based on model predictions with only limited verification from actual measurements of soil erosion.

Of the four identified types of soil erosion (water, wind, tillage and co-extraction) in England and Wales, erosion by water is the most extensive. Wind erosion mainly affects sandy and peaty soils in the eastern and middle counties of England, and upland areas of England and Wales. Although erosion by water may be spatially more dominant, erosion by wind can cause greater loss of soil per unit of land when it occurs. Erosion by tillage and through co-extraction remains poorly understood with almost no available scientific data for England and Wales.

Drawing on available literature, NSRI data sources and expert judgement, Table 5 shows the assessment of the assumed relative probability or erosion by soilscape in England and Wales erosion. The likely incidence and magnitude of erosion is high on non-clay soils under horticulture, arable cropping and improved grassland.

#### Table 5  The assumed relative probability of erosion by soilscape in England and Wales

<table>
<thead>
<tr>
<th>Land use</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
<th>Peat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>L</td>
<td>H</td>
<td>H</td>
<td>n/a</td>
</tr>
<tr>
<td>Horticulture</td>
<td>L</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Arable intensive</td>
<td>L</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Arable extensive</td>
<td>L</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Grassland improved</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>Grassland unimproved</td>
<td>L</td>
<td>M</td>
<td>M</td>
<td>H</td>
</tr>
</tbody>
</table>

\(^{19}\) See Appendix D  
\(^{20}\) Silsoe Whole Farm Model:  http://www.cranfield.ac.uk/sas/naturalresources/research/projects/silsoewholefarmmodel.html  
\(^{25}\) Probability of occurrence here is taken to be a measure of the magnitude/intensity of a degradation process, which combines aspects of the relative incidence across a soilscape and the intensity of the degradation process where it occurs. It was hoped to separate out probabilities and intensity, for example by constructing an estimates of mean and variance of degradation processes within a landscape. This was not possible with the information available, although it might be possible using a modelling approach.  
\(^{26}\) Appendix C reviews our present level of understanding of the extent and intensity of the six identified soil degradation processes for England and Wales.
6.2 Compaction
Field measurements of the extent and severity of soil compaction in England and Wales are limited\(^{27}\)\(^{28}\)\(^{29}\)\(^{30}\). Maps of estimated vulnerability and risk of compaction for grasslands across England and Wales have been produced but are limited by the available data sets, both in terms of accuracy and sensitivity. The probability of soil compaction is particularly high on clays, but also has a high chance of incidence on sands (Table 6).

<table>
<thead>
<tr>
<th>Land use</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
<th>Peat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>H</td>
<td>H</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Horticulture</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Arable intensive</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>M</td>
</tr>
<tr>
<td>Arable extensive</td>
<td>H</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Grassland improved</td>
<td>H</td>
<td>L</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Grassland unimproved</td>
<td>M</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Rough grassland</td>
<td>M</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Forestry</td>
<td>H</td>
<td>L</td>
<td>M</td>
<td>M</td>
</tr>
<tr>
<td>Woodland</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>Wildscape</td>
<td>L</td>
<td>L</td>
<td>L</td>
<td>L</td>
</tr>
</tbody>
</table>

The assessment of degradation probabilities was combined (see Figure 1) to generate spatial distributions of degradation probability. Figure 4 shows these for erosion and compaction.

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\(^{27}\) Palmer RC. 2004. Soil structural conditions in the axe and char catchments during march 2004. NSRI research report No. YSR 9127V for FWAG (Devon) and Environment Agency, 36p

\(^{28}\) For an extensive review of literature on compaction effects see - Chamen, W.C T. (2011) The Effects of Low and Controlled Trffic Systems on Soil Physical properties, Yields and the Profitability of Cereal Crops on a Range of Soils. Unpublished PhD, Cranfield University, Bedford

\(^{29}\) Defra Project BD2304 (2007). Scoping study to assess soil compaction affecting upland and lowland grassland in England and Wales

6.3 Probability of other degradation processes

The above approach was applied to the other degradation processes (see Appendix C). Loss of soil organic content and soil biota are more likely to occur on farmed land and least on forestry, woodland and wildscapes. The extent of the total stock of carbon is reasonably well known for Wales and for agricultural areas in England and Wales. The intensity of loss of organic matter has been estimated from the NSRI archive that compares soil samples taken in the original survey and those collected in a partial resurvey. The changes in soil carbon across England and Wales measured in the National Soil Inventory (NSI) have not, however, been detected in the Countryside Survey. The reasons for this are being investigated in a continuing project funded by Defra.

The potential threat to soil biodiversity in most parts of England and to a lesser extent in Wales is high primarily because of the effect of high intensity agriculture, soil compaction, risk of erosion and loss of soil organic matter content.

Diffuse contamination can affect all soilscapes, although this varies according to the type of pollutants, the pollution pathway, the persistence of the contaminants and the neutralising ability of soilscapes. Knowledge of the spatial extent of diffuse contamination of soil is mainly limited to zinc and copper contents related to the application of animal manures, domestic sludge and paper waste on agricultural land. However, the probability of sea level rise and could increase salt water intrusion in coastal areas. Deposition of airborne pollutants mainly concerns fallout from Chernobyl and acidification from industrial pollution.

Sealing is predominantly associated with the urban built soilscape, although this may apply in a rural context, and where compaction of farm land is severe. The extent of surface sealing is evident in the growth of urban areas, settlements and communication networks. Recent growth in surface sealing has mainly occurred in pre-existing urban areas and relatively small areas of greenfield land have been developed (i.e. in England 5,000 ha per annum between 2000 and 2006).

Figure 4 Spatial distribution of predicted probability of soil erosion (left) and compaction (right) in England and Wales

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31 SP1101: Comparison of soil carbon changes across England and Wales estimated in the Countryside Survey and the National Soil Inventory
6.4 Combined effects
It is noted that soil degradation processes are not independent. Soil erosion and compaction, for example often occur on the same site, sharing similar causes and generating similar effects. Compaction by tractor wheelings for example can exacerbate the overland flow of water during storm events, leading to erosion. Both of these processes may be associated with loss of soil organic content and soil biota, increasing the overall rate of degradation. The approach here considers degradation processes independently, noting that they may apply simultaneously and overlap in their effects. Care is taken to avoid double counting of impacts, focusing on dominant sources of degradation where these occur.
7 The Total Costs of Soil Degradation in England and Wales

This section presents the estimates of the costs of soil degradation in England and Wales. Where possible these are measured in monetary values (£2010).

7.1 The costs of soil erosion

The identified costs of erosion include: (i) the onsite costs of the decline in agricultural and forestry yields caused by the reduction in soil depth, the cost of a reduction in the stock of C, and the cost of replacing losses in N, P and K, and (ii) the offsite cost associated with impacts on environmental water quality, drinking water quality, and greenhouse gas regulation.34 Case Example A (i) illustrates the impacts of erosion.

Measured erosion rates do not exist at a national scale and the most extensive data on quantified erosion rates at a national scale in England and Wales are held by the National Soil Resources Institute (previously Soil Survey of England and Wales) and the Agricultural Development and Advisory Service (ADAS). A review by Owens et al35 of different forms of erosion concluded that wind erosion, soil loss at crop harvest and tillage erosion contribute relatively little soil loss to national erosion rates compared with erosion by water and we therefore focus on quantification of rates of soil erosion by water.

Estimates of typical rates of erosion for the landuse/soil type categories were taken from a variety of data sources, including experimental data and peer reviewed literature. Typical rates for the landscape/soil type categories were developed using these data or defined using expert opinion (Table 7).

Table 7. Selected erosion rates (t ha-1 yr-1) used for each Land use/soil type category

<table>
<thead>
<tr>
<th>Land use</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
<th>Peat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>0</td>
<td>10</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Horticulture</td>
<td>2</td>
<td>20</td>
<td>5.08</td>
<td>15</td>
</tr>
<tr>
<td>Arable intensive</td>
<td>1.92</td>
<td>22.4</td>
<td>20.3</td>
<td>20</td>
</tr>
<tr>
<td>Arable extensive</td>
<td>1</td>
<td>6.3</td>
<td>3.46</td>
<td>10</td>
</tr>
<tr>
<td>Grassland improved</td>
<td>0.36</td>
<td>4.49</td>
<td>4.09</td>
<td>7</td>
</tr>
<tr>
<td>Grassland unimproved</td>
<td>1.29</td>
<td>2.07</td>
<td>1.5</td>
<td>10</td>
</tr>
<tr>
<td>Rough grassland</td>
<td>0.05</td>
<td>0.75</td>
<td>0.22</td>
<td>10</td>
</tr>
<tr>
<td>Forestry</td>
<td>0.01</td>
<td>0.5</td>
<td>0.05</td>
<td>0.7</td>
</tr>
<tr>
<td>Woodland</td>
<td>0.01</td>
<td>0.5</td>
<td>0.05</td>
<td>0.7</td>
</tr>
<tr>
<td>Wildscape</td>
<td>0.05</td>
<td>0.5</td>
<td>0.05</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Erosion was considered to occur only on a proportion of the total land area in each category each year. Whilst estimates of the area at risk of erosion vary by crop, typically, about 17% of arable soils show signs of erosion although 40% is considered to be at risk of erosion.37 There appears to be relatively little erosion research on grassland systems.38 There appears to a consensus that relatively small amounts of erosion occur on grassland,40 41 42 due to the high level of surface cover, but it can be locally problematic.43 C values, which give the rate of

34 The assumptions behind the estimates of costs for soil erosion are fully explained in Appendix F.
39 Bilotta et al , cited above
erosion for different land use systems relative to bare ground\textsuperscript{44}, are generally low for grass cover. Evans\textsuperscript{45} suggested a zero occurrence of erosion for temporary grass. In Scotland, however, about 12\% of uplands are considered at risk of erosion\textsuperscript{46}. Based on these various considerations, the area subject to erosion on improved grassland was assumed to be 5\% whilst the area on unimproved and rough grassland was considered to be 2\% to reflect lower stocking rates. The area of other land uses/soil type categories considered to be at risk of erosion each year were assumed to be 1\%\textsuperscript{47}.

**Case A**

(i) **Muddy Floods associated with erosion and run off from intensive root cropping on hillslopes: Kenton, East Devon**

A storm event in May 2008 at Leyson, near Kenton, Exeter (32 mm in 1 hour, a 28 year return period) resulted in runoff from a 30 ha carrot field that led to a muddy flood and damages to 4 houses (insurance costs £450,000) and clean up and remedial costs to Devon County Council (c £50,000). Field inspection confirmed the effects of cultivations down the hillslopes and compaction of tractor wheelings and headlands. Subsequent mitigation measures and costs included field bunds, culvert replacements and household protective walls/gates.

(ii) **Flooding from compacted maize silage fields, Cadhay Estate, East Devon**

Soil erosion, runoff and extensive movement of coarse sediment occurred on the Cadhay Estate following a storm event in 2008 with widespread damage to estate infrastructure (bridges, tracks, roads) and flooding of property. Relatively well structured soils with cover of early planted wheat (left) did not exhibit high rates of run-off and erosion compared with late harvested, compacted maize fields (centre and right)

Source and Acknowledgment: Richard Smith, Principal Officer Land Quality Environment Agency SW


\textsuperscript{47} see Appendix F
Table 8 Estimated cost of soil erosion in England and Wales – all soilscapes

<table>
<thead>
<tr>
<th>Physical data</th>
<th>Erosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total areas at risk within categories (ha)</td>
<td>1,022,459</td>
</tr>
<tr>
<td>National soil erosion (t yr⁻¹)</td>
<td>2,920,626</td>
</tr>
<tr>
<td>Average national soil erosion (t ha⁻¹ yr⁻¹)</td>
<td>0.21</td>
</tr>
<tr>
<td>Soil N loss (t yr⁻¹)</td>
<td>18,026</td>
</tr>
<tr>
<td>Soil P loss (t yr⁻¹)</td>
<td>4,830</td>
</tr>
<tr>
<td>Soil K loss (t yr⁻¹)</td>
<td>38,280</td>
</tr>
<tr>
<td>Soil C loss (t yr⁻¹)</td>
<td>225,787</td>
</tr>
</tbody>
</table>

On-site costs

| Total E&W productivity loss due to erosion (£) | £000 5,358 |
| Total E&W N loss cost due to erosion (£) | 11,176 |
| Total E&W P loss cost due to erosion (£) | 3,284 |
| Total E&W K loss cost due to erosion (£) | 19,906 |
| Total E&W C loss cost due to erosion (£) | 151 |

Off-site costs

| Cost of N in drinking water (£) | £000 3,100 |
| Cost of sediment removal in drinking water (£) | 44,978 |
| Cost of N in rivers and lakes (£) | 2,902 |
| Cost of P in transitional waters (£) | 160 |
| Cost of P in freshwater lakes (£) | 6,796 |
| Cost of sediment removal in rivers & canals (£) | 15,041 |
| Cost of sediment removal in urban drainage (£) | 55,000 |
| GHG cost of soil C loss (£) | 8,452 |

Total costs

| Total onsite cost | £000 39,874 |
| Total offsite cost | 136,430 |

Using these data, the erosion in England and Wales was calculated to be approximately 2.9 Mt yr⁻¹, which is similar to the 2.2 Mt yr⁻¹ estimate given by the Environment Agency. The majority of this erosion is associated with silts and sands, especially on arable and horticultural land, where mean per hectare erosion rates are also highest. An estimated 1 million ha are at risk of erosion in England and Wales, mainly associated with arable farming on silts and sands. Overall average loss is low at 0.21 t ha⁻¹ a⁻¹.

The total annual cost of erosion in England and Wales for all soilscapes is about £177 million yr, of which about 23% are onsite costs and 77% are offsite costs (Table 8). Onsite costs (£40 million per year) comprise loss of yield potential due to loss of soil medium and loss of soil nutrients valued at their chemical nutrient replacement cost.

Offsite costs (£136 million per year) comprise mainly the treatment cost of nutrient removal from drinking water, the damage costs of nutrients passing to the water environment, sediment removal from rivers and lakes, sediment removal from urban drainage systems, and GHG loss linked to erosion events. The estimate for the cost of removing silt from urban drainage (at £55 million/year) is taken from the Soil Strategy for England, also referred to Environment Agency (2007). It was not possible to confirm the basis for this estimate. It appears high relative to the costs of dredging and silt removal from rivers reported by the Environment Agency at about £10 million/year, and from navigations by British Water Ways at £5 million/year. Internal Drainage Boards also include silt removal in their programmes of water course desilting/re-profiling, usually conducted at 15-20 year intervals. Offsite flood damage costs associated with muddy floods generated on farm land are attributed to compaction.

7.2 The costs of compaction

The cost of compaction was considered to include: the onsite cost of agricultural and forestry yield decline caused by impaired rooting medium and reduced water holding capacity, the extra draught power associated with ploughing and cultivation operations, and the cost of losing applied N, P, and K because of extra runoff. The off-site costs included the impact of compaction induced additional N, P and K in the water environment and the environmental burdens associated with increased soil tillage. Case A (ii) illustrates the impacts of compaction.

---

49 Discussions with LGA engineers in Cambridgeshire and Buckinghamshire was not able to separate costs for soil erosion related.
50 This estimate is not included at the moment.
51 See Appendix G:
The degree and severity of compaction varies according to land use and soil type. However, there are little data available that can be used to distinguish between these categories. The areas liable to compaction were estimated for each soilscape, allowing for variations in field size, field operations, machine turning on headlands, in field ‘tramlines’, and trafficing in the general field area. The areas and yield decline associated with each type of compaction was estimated by using literature (e.g. Defra project BD2304\textsuperscript{52}, BD5001\textsuperscript{53}, Chamen\textsuperscript{54}, Palmer 2004\textsuperscript{55}) and personal communication \textsuperscript{56}. The impact of compaction on crop yields was generally assumed to be greatest on clays and lowest on silts for headland and general field compaction. Tramlines developed for field operations during crop growth were assumed to totally inhibit crop growth and 33\% of this cost was assumed to be associated with managing compaction risk. The areas affected by compaction and the integrated yield loss associated with compaction are shown in Table 9.

Table 9. Estimates of areas liable to compaction, and associated yield loss on the compacted area by soilscape

<table>
<thead>
<tr>
<th>Land use</th>
<th>% area affected by compaction</th>
<th>Yield loss on compacted area (%)*</th>
<th>Soilscape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>0%</td>
<td>0%</td>
<td>Clay 0%</td>
</tr>
<tr>
<td>Horticulture</td>
<td>41%</td>
<td>6%</td>
<td>Silt 3%</td>
</tr>
<tr>
<td>Arable intensive</td>
<td>42%</td>
<td>5%</td>
<td>Sand 4%</td>
</tr>
<tr>
<td>Arable extensive</td>
<td>42%</td>
<td>5%</td>
<td>Peat 4%</td>
</tr>
<tr>
<td>Grassland improved</td>
<td>39%</td>
<td>3%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Grassland unimproved</td>
<td>38%</td>
<td>3%</td>
<td>1%</td>
</tr>
<tr>
<td>Rough grassland</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Forestry**</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Woodland</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Wildscape</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
</tbody>
</table>

*Yield losses weighted according to losses on headlands and general field areas, assuming 1/3 of yield loss on tramlines is attributable to compaction mitigation ** varies according to development phase

Compacted soils require extra draught power for tillage and seed bed preparation, resulting in increased costs. Extra fuel consumption and hours of operation were estimated for compaction different soil types, drawing on reported machinery costs, research literature and expert opinion.

Compaction results in the loss of nutrients to crops because of increased runoff. Here it is assumed that these affect applications of N, P, and K in fertiliser equally. These nutrients are valued at cost.

The extra use of diesel and fertilisers are also associated with a range of environmental burdens linked to their manufacture and emissions of nutrients to water and GHG to atmosphere. These impacts were valued in terms of estimated costs of damage of freshwater due to eutrophication, water treatment or carbon abatement\textsuperscript{57}. Case B contains an example of the impacts of soil degradation on the freshwater environment and resources.

Soil compaction can, by reducing the permeability of the land surface, increase the probability of runoff and flood generation. Studies in the UK (O’Connell et al., 2004, 2007\textsuperscript{58}; Environment Agency, 2008\textsuperscript{59}; Salazar et al., 2009\textsuperscript{60})

\textsuperscript{52} Defra project BD2304 - Scoping study to assess soil compaction affecting upland and lowland grassland in England and Wales: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=14699

\textsuperscript{53} Defra project BD5001 - Characterisation of soil structural degradation under grassland and development of measures to ameliorate its impact on biodiversity and other soil functions: http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=16827


\textsuperscript{55} Palmer RC. 2004. Soil structural conditions in the axe and char catchments during march 2004. NSRI research report No. YSR 9127V for FWAG (Devon) and Environment Agency, 36p.

\textsuperscript{56} Professor R. Godwin and Dr T. Chamen.

\textsuperscript{57} See Appendix F.


\textsuperscript{59} Environment Agency 2008 opcit

\textsuperscript{60} Salazar, S., Frančes, F., Komma, J., Blöschl, G., Blume, T., Franke, T. and Bronstert, A. 2009. Efficiency of non-structural mitigation measures: “room for the river” and “retaining water in the landscape”. In Flood Risk Management: Research and Practice. Samuels et al. (eds). Taylor & Francis Group. London.
report evidence of a link between land and soil management and flood generation at the farm and small sub-catchment scale (<10km²) – apparent for example in the incidence of local ‘muddy’ floods (e.g. Boardman, 2003b) (See case B below). There is currently limited evidence, however, to confirm the relationship between land use, soil condition and flood generation for the more extreme events at the catchment scale (O’Connell et al., 2007; Beven et al. 2008). This does not mean that there is no relationship, rather that available data and modelling capability cannot readily confirm one. Nevertheless, it is a widely held view that agricultural intensification has been associated with increased flood probability, and that appropriate land management to “retain water in the landscape” could contribute to flood risk mitigation (Hess et al., 2010).

For the purpose of assessing the relationship between soil degradation and flood risk, a catchment flood management tool containing information on catchment flood areas, land cover and soil (HOST) classes, was used to assess the impact of changes in soil condition on relative changes in the mean depth of runoff (mm) from land for given rainfall return period events. This showed that soil degradation particularly associated with compaction could be responsible for between 3% and 10% increase in the depth of run off for the 75 year event across a range of soils. A switch from a predominantly ‘fair’ to a ‘good’ soil management scenario on agricultural land uses are known to be associated with more rapid run off than others, as referred to earlier. The soilscape data were available in the CFMP tool, suggested a reduction in the average depth of runoff (mm) of about 10% for median annual rainfall event and about 7% reduction for the 75 year return period rainfall event. The latter is assumed to be associated with the threshold flood event that presents a serious risk to property.

Currently, the estimated total annual costs of flood damage in England and Wales are about £1.4bn, with a further £1bn spent on flood risk management: a total of £2.4 bn per year. Currently about 550,000 households are at serious risk of flooding that is more often than a 1.3% chance in any one year. A further 5 million properties exposed to moderate to low probability of flooding (between 0.5% and 1.3% chance of flooding each year). Climate change, however, could increase their exposure to flood risk.

Assuming simplistically that changes in soil condition affect runoff for all return period rainfall events, and is associated with an equivalent change in the probability of flooding at the catchment scale, soil degradation could be responsible for between £72 million (3%) and £240 million (10%) flood damage and risk management costs per year, with a central estimate of £168 million/year (based on a 7% increase in flood risk). It is noted that the approach adopted here specifically attributes changes in flooding to changes in soil condition (for given land uses). Some agricultural land uses are known to be associated with more rapid run off than others, as referred to earlier. The estimate of £168 million compares with the estimate by the Environment Agency (2002) that attributed about 14% of flood events and direct flood damage costs (£1.4 bn per year) with run-off from farm land, producing an estimate of about £200 million per year (£336 million if all £2.4 bn flood risk management costs are assumed).

An estimated 3.9 million ha are at risk of compaction in England and Wales, highest on clay soils during wet periods. The estimated total cost of compaction (Table 10) is £472 million per year, about half of which are on-site, and half are offsite. Of the £204 million per year on site costs, the majority are associated with yield loss on compacted ground and loss of N associated with runoff from compacted surfaces (£23 million). Of the £268 million per year offsite costs, the majority (£168 million) is associated with flood damage and flood risk management costs. The other major off site costs relate to the costs of emissions to water and atmosphere and associated cost of water treatment, damage to the water environment, and GHG emissions from production of the fertiliser that is lost due to compaction as well as the fraction that converts to N₂O (£74 million) and NH₃ (£3 million) during denitrification.

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67 Environment Agency. 2009b Flooding in Wales, Environment Agency, Cardiff
It is noted that the estimated total annual costs compaction are nearly three times greater than those of erosion, reflecting its greater presence in the landscape.

Table 10 Estimated cost of soil compaction in England and Wales – all soilscape

<table>
<thead>
<tr>
<th>Physical data</th>
<th>Compaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total areas at risk within categories (ha)</td>
<td>3,858,670</td>
</tr>
<tr>
<td>Fertiliser N loss (t yr^-1)</td>
<td>37,044</td>
</tr>
<tr>
<td>Fertiliser P loss (t yr^-1)</td>
<td>979</td>
</tr>
<tr>
<td>Fertiliser K loss (t yr^-1)</td>
<td>1,751</td>
</tr>
<tr>
<td>C loss (t yr^-1)</td>
<td>-</td>
</tr>
<tr>
<td>Additional diesel use (l yr^-1)</td>
<td>41,611,174</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>On-site costs</th>
<th>£,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total E&amp;W productivity loss due to compaction (£)</td>
<td>161,670</td>
</tr>
<tr>
<td>Total E&amp;W N loss cost due to compaction (£)</td>
<td>22,697</td>
</tr>
<tr>
<td>Total E&amp;W P loss cost due to compaction (£)</td>
<td>666</td>
</tr>
<tr>
<td>Total E&amp;W K loss cost due to compaction (£)</td>
<td>911</td>
</tr>
<tr>
<td>Total E&amp;W cost of additional diesel penalty (£)</td>
<td>17,477</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Off-site costs</th>
<th>£,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of N in drinking water (£)</td>
<td>2,166</td>
</tr>
<tr>
<td>Cost of N in rivers and lakes (£)</td>
<td>2,028</td>
</tr>
<tr>
<td>Cost of N in transitional waters (£)</td>
<td>112</td>
</tr>
<tr>
<td>Cost of P in freshwater lakes (£)</td>
<td>1,377</td>
</tr>
<tr>
<td>GHG cost of increased N loss (£)</td>
<td>9,446</td>
</tr>
<tr>
<td>GHG cost of increased P loss (£)</td>
<td>50</td>
</tr>
<tr>
<td>GHG cost of increased K loss (£)</td>
<td>45</td>
</tr>
<tr>
<td>GHG cost of diesel penalty (£)</td>
<td>6,579</td>
</tr>
<tr>
<td>GHG cost of N as NO2 (£)</td>
<td>73,627</td>
</tr>
<tr>
<td>GHG cost of N as NH3 (£)</td>
<td>3,458</td>
</tr>
<tr>
<td>Flooding cost (£)</td>
<td>168,000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Total costs</th>
<th>£,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total onsite cost</td>
<td>203,691</td>
</tr>
<tr>
<td>Total offsite cost</td>
<td>268,468</td>
</tr>
</tbody>
</table>
Case B
Case study: Upstream Thinking – South West Water

Climate change and pressures for intensive agriculture are affecting the quality and quantity of raw water supplies collected in reservoirs and abstracted from rivers. South West Water (SSW) promoted two series of actions from 2006 to 2009 to develop responses to this based on moorland restoration on Exmoor and reducing soil loss and pollution from farms and has now developed a long term response which is being implemented.

Ditch construction and drainage schemes in the past improved the land for agricultural purposes, but loss of natural water storage has led to significant erosion, carbon dioxide release from drying peat, biodiversity loss and increased downstream flood risks. A restoration project was started on Exmoor in 2003 by Exmoor National Park Authority and South West Water provided additional funding from 2006 onwards. To date over 320 hectares of moorland have been restored with a wide range of hydrological and environmental benefits. Changes in grazing yields are offset by support payments from Natural England to the landowners involved. The Environment Agency is providing an extensive hydrological investigation to confirm the benefits.

A group of 15 farms were improved above one of the most damaged reservoirs, Upper Tamar Lake near Bude. Similar techniques were undertaken to those of the England Catchment Sensitive Farming Delivery Initiative, with funds mainly provided by the Tubney Charitable Trust, to reduce soil erosion, loss of nutrients, reduce damage caused by the access of stock to watercourses and improve water quality.

A more extensive programme of changes to uplands and farmed land was promoted in the last Period Review (PR09) with support from Ofwat and the Consumer Council for Water. A 3,000 hectare restoration on Exmoor, a 110 hectare trial on Dartmoor and seven catchment scale farmland improvements above key intakes and reservoirs are underway. £0.7m is being spent on 15 two-year catchment investigations to develop further schemes for inclusion in the PR14 Business Plan. According to SWW, clean raw surface water costs 20% less to treat than water with heavy sediment loads, avoiding costly longer-term water treatment investment. When assessed over 30 years in line with Ofwat’s instructions for PR09, the programme is estimated to offer a benefit to cost ratio of 65:1 or better. ‘Soft engineering’ for flood protection which complements conventional defences for urban areas.

The current improvement programme for moorland and catchments raises £8.1m for local projects to restore the natural water storage ability of uplands and limit the damage to rivers from farmland from 2010 to 2015. These projects are included in the South West River Basin Management Plan as they will contribute to ‘Good Status’ delivery for the Water Framework Directive. Moorland restoration offers carbon capture at about 12 tonnes CO₂/hectare/year while farmers are being encouraged to create wetlands and biodiversity areas with the Woodland Trust’s support. The cost to our water customers is an additional 65p on bills by 2015, compared to a customers’ willingness-to-pay identified in PR09 of £2.40 for additional environmental projects. Our delivery partners are Rivers and Wildlife Trusts and others with a network of local experts and volunteers able and willing to identify risks and engage landowners in remedial action.

Source and Acknowledgment: Martin Ross: Environmental Manager, South West Water. mross@southwestwater.co.uk
7.3 Loss of Organic Content

There is much concern about the loss of soil carbon to atmosphere and its consequences for global warming and climate change\textsuperscript{72}. The annual loss of organic matter from the soils in England and Wales was estimated using data from the NSI database described and developed by Bellamy et al\textsuperscript{73}. Drawing on field measurements of carbon in the top 15 cm of soils on the same sites carried out between 1978 and 1983 and subsequently between 1994 and 1995, estimates were derived of the rate of change in terms of the original C content of the soil, measured in units of g of C per kg soil per yr.

Table 11 Estimated cost of soil compaction in England and Wales – all soilscape

<table>
<thead>
<tr>
<th>Topsoil C content (0-15cm)</th>
<th>Rate of change in topsoil C content (0-15cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(g C kg\textsuperscript{-1} soil yr\textsuperscript{-1})</td>
</tr>
<tr>
<td>&gt;0, &lt;=20</td>
<td>0.34</td>
</tr>
<tr>
<td>&gt;20, &lt;=30</td>
<td>0.13</td>
</tr>
<tr>
<td>&gt;30, &lt;=50</td>
<td>-0.10</td>
</tr>
<tr>
<td>&gt;50, &lt;=100</td>
<td>-0.68</td>
</tr>
<tr>
<td>&gt;100, &lt;=200</td>
<td>-2.18</td>
</tr>
<tr>
<td>&gt;200, &lt;=300</td>
<td>-4.00</td>
</tr>
<tr>
<td>&gt;300</td>
<td>-7.37</td>
</tr>
</tbody>
</table>

The NSI topsoil data were intersected with the spatial landuse/soil type dataset\textsuperscript{74} and the mean total carbon content of the soils calculated from this dataset. The mean rate of change was then calculated for each of the land use/soil type categories using the relationship between Topsoil C content (g kg\textsuperscript{-1} soil C) and the rate of change (g C kg\textsuperscript{-1} soil yr\textsuperscript{-1}) data provided in Bellamy et al\textsuperscript{75} (Table 11). The mean rate of change was negative across all the landuse/soil type categories, with C loss greater on a per weight basis on peat soils. Using this approach, the total estimated C lost from the soil each year in England and Wales is 5.3 Mt year, much of it from clays and peats.

The loss of soil C has both onsite implications for agricultural production and offsite implications for global warming (Table 12). Soil organic matter, for which soil organic C is a proxy, is critical for good soil structure. From this, there are numerous benefits, such as improved workability of the soil, crop germination, water holding capacity, resistance to compaction, increased crop productivity have been reported\textsuperscript{76}. The annual cost of the loss of organic matter in the soil as measured by loss of organic C was calculated to be £3.5 million per year, based on the cost of replacing it with organic manures.

The off-site cost in terms of GHG emission was hugely more significant. It is assumed that all soil organic matter degrades at a constant rate and that 80% of the cellulose and 30% for lignins find their way to atmosphere as reported by Abad et al\textsuperscript{77}. The rest it was assumed would move to deeper soil layers or into water bodies. Using the ratio of 1 to 3.67 for soil C to CO\textsubscript{2} in the atmosphere, the central estimated annual cost , assuming a CO\textsubscript{2} value of £51 CO\textsubscript{2}e/t is £566 million mostly associated with clay and peat soils, ranging between low and high estimates of £360 million and £700 million per year respectively.

The costs of GHG emissions induced by changes in soil organic content are very high in comparison with other degradation effects. It is noted that all the parameters in the estimate are liable to large estimation errors, namely: rates of loss, bulk density, the fate of emissions, and the unit price of carbon (measured here at the cost of GHG abatement). For this reason the estimate needs to be treated cautiously.

Table 12 The estimated costs of loss of soil organic content in England and Wales

<table>
<thead>
<tr>
<th>Physical data</th>
<th>On-site costs</th>
<th>Off-site costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil C loss (t yr\textsuperscript{-1})</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5,260,886</td>
<td>£,000</td>
</tr>
<tr>
<td>Total E&amp;W C loss cost due to erosion (£)</td>
<td>3,507</td>
<td></td>
</tr>
<tr>
<td>GHG cost of soil C loss (£)</td>
<td></td>
<td>£,000</td>
</tr>
<tr>
<td></td>
<td>566,124</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{72} See Appendix O for a case study of restoration of peat soils to address degradation associated with intensive farming.


\textsuperscript{74} see Appendix D


\textsuperscript{76} KeySoil: http://www.keysoil.com/

\textsuperscript{77} Abad, M, Patricia Noguera, Rosa Puchades, Angel Maquieira and Vicente Noguera (2002). Physico-chemical and chemical properties of some coconut coir dusts for use as a peat substitute for containerised ornamental plants. Bioresource Technology, Volume 82, Issue 3 Pages 241-245

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7.4 The costs of soil diffuse contamination

The range of contaminants in soils is large. The major groups of contaminants that are potentially toxic to the soil system itself and to humans and the wider environment include nutrients, specifically nitrogen and phosphorus, metals and metalloids such as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cd), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn) together with certain anions such as cyanide, trace organic micropollutants (TOMPs), such as dioxins, furans, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls (PCBs), and agricultural pesticides.

On the whole, the location of diffuse contamination reflects that of anthropogenic sources and their location reflects access to transport, historic precedence, and other factors. Large areas of England and Wales for example, are considered to exceed critical loads for acidity and nutrient N, despite significant reductions or sulphur dioxide (82% between 1990 and 2006) and nitrogen oxides (46% between 1990 and 2006) emissions, and the impact that this has had on soils is therefore considered to be a historical impact, rather than attributable to current levels of diffuse pollution.

A similar view can be taken with other forms of diffuse pollution. Whilst historic contamination incurs remediation costs, this is a cost from the past and not attributable to current diffuse pollution. The counterfactual that we assumed in this analysis is therefore considered to be the cost of soil degradation caused by current diffuse pollution, rather of historic diffuse pollution.

Under this assumption, there appears to be little evidence of any significant costs associated with current levels of diffuse contamination to the soil. This reflects the mature and strong regulatory framework for preventing this new contamination. In some respects, it could be argued that if there is a current cost, it is in the cost of running this regulatory system in order to prevent the impacts of further diffuse pollution.

Current rates of diffuse contamination of soils are low due to a comprehensive regulatory system. The Environment Agency spent £253 million during 2010-2011 on environmental regulation to protect water, land and air. A portion of this regulatory cost, possibly of the order of 10%, is probably linked to controlling contamination of soil, equivalent to a cost of £25 million per year.

7.5 The cost of loss of soil biota

The structure and processes of terrestrial ecosystems are profoundly dependent upon a functioning soil biota. Such ecosystem services include, soil organic matter cycling and fertility, soil structural formation and maintenance, regulation of carbon flux and feedback to climate, regulation of the water cycle, decontamination and bioremediation, and pest control. Multiple services can be provided by single species of soil organisms, which makes it almost impossible to disentangle the effects of a particular species on a particular function. Consistent relationships between soil biodiversity and specific soil functions have yet to be demonstrated, suggesting that more species do not always provide more services, most likely because of a high degree of functional redundancy.

Soil biota is sensitive to a number of abiotic and biotic factors. Generally, as the size of soil organisms decrease, then their susceptibility to physical disturbance tends to decrease. In this sense relatively large organisms such as earthworms are readily killed by cultivation, and civil engineering operations. Fungi are also susceptible. Bacteria are relatively unaffected by the direct effects of cultivation but are impacted by consequent changes in soil conditions.

79 See Appendix J
In the majority of studies soil biota have been shown to reflect the pressures and changes in the rest of the ecosystem arising from human activity and rarely to drive or facilitate such change. There are few examples of specific distinct links that can made between soil biota and alterations in flows of ecosystem services, although the relationship could be associated with other degradation processes. Pimental et al (1995), for example, attributed a 20% yield decline over 20 years in the USA to soil erosion, with 1% of this yield decline potentially due to soil biota degradation. Critically however, we argue that since the role of soil biota are essential part of the supporting ecosystem services (e.g. soil formation and nutrient cycling) which underlie production, regulating, and cultural services, the cost of degradation in soil biota is captured through the delivery of a variety of final provisioning, regulating and cultural ecosystem services.

Soil biota losses are greatest where intense cultivation, inorganic fertiliser, biocide use, and contamination are greatest – but these costs are probably already captured in the costs for erosion, flood risk, compaction and yield losses already calculated. It is currently impossible to ascribe even qualitative relationships between soil biodiversity loss and loss in service values (Turbe et al, 2010). However, we must also recognise that many aspects of soil biodiversity are central to the fundamental operation of ecosystems.

The cost of soil sealing

Soil sealing involves covering soils with an impermeable layer and hence compromising their ability to support beneficial ecosystem services. Sealing is most severe in the built urban environment where soils are covered by impermeable materials which affect their ability to transfer water and air from the atmosphere, and particularly their capacity to attenuate surface flows of water during extreme rainfall events. Thus the costs of soil sealing reflect the curtailment of services that otherwise would be provided, especially but not exclusively linked to hydrological regulation.

About 11% of the surface area in England and Wales is classed as ‘developed’ land, characterised by a built environment (Foresight, 2010). Of this, about 3% is actually built on, the balance being mainly gardens and open spaces. Recent development has mainly occurred in pre-used ‘brown field’ areas. Relatively small areas of greenfield land have been developed (i.e. in England 5,000 ha per annum between 2000 and 2006; Foresight, 2010). There has however been a tendency towards increased sealing within existing urban areas, especially for car parking. The London Assembly, examined aerial photographs of the capital in 2005 and found that 67% of the total area of front gardens in Greater London had been paved, accounting for 32 square kilometres and 3% of the total metropolitan land area: equivalent to 22 Hyde Parks.

Most effects operate at the local and catchment scale, particularly regarding impact on water and nutrient cycles. The most economically significant impact of urban sealing is on the regulation of water flows. Sealing increases the probability of flooding and also the costs of damage when flooding occurs. Reduced surface sealing, and related attenuation works, could help to reduce flood damage costs or save investment in conventional urban drainage (and water treatment) systems.

It is not possible to determine the proportion of the current £1.4 bn flood damage costs and £1 bn flood risk management costs could be saved by reducing the extent of soil sealing. However, the Environment Agency estimated that two-thirds of the 55,000 homes and 8,000 businesses affected by the summer 2007 flooding were flooded because drains, culverts, sewers and ditches were overwhelmed, equivalent to insurance claims of about £2bn. A proportion of this could be attributed to excessive surface sealing which renders the drainage system inadequate during extreme events. Case C below illustrates the use of Sustainable Urban Drainage (SUDS) to maintain soil hydrological functions, simultaneously providing other services such as green space for amenity and nature conservation. The Oxley Park Development in Milton Keynes provides another example.

88 Defra (2007) An introductory guide to valuing ecosystem services. 68pp
89 Millennium Ecosystem Assessment 2005. Ecosystem services and human wellbeing. Synthesis report. 155 pp
93 Foresight (2010). As cited above
96 See Appendix L - Milton Keynes, Buckinghamshire for a case study of soils in an urban context.

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There is currently insufficient knowledge to assess the potential significant economic impacts of soil sealing at the local or national scale. It is valid area for research, especially regarding the hydrological functions of soils, SUDS and development regulation, and in the context of predicted climate change97.

**Case C: Sustainable Urban Drainage, Cambridgeshire**

Sustainable Urban Drainage Systems (SUDS) are an alternative to conventional engineered solutions. SUDS involves minimising the sealing of soil surfaces and retaining part or all of the hydrological functions of soils in an urban environment, notable the regulation of flooding. SUDs can also support other soil functions and benefits such as biodiversity (below and above ground), water purification, carbon sequestration, and ‘green space’ recreation.

Cambridgeshire County Council and Cambridge Housing Society have sponsored the Lamb Drove SUDS Residential Scheme, comprising 35 affordable homes on a 1 ha site. Here, SUDS mimics the natural drainage processes of soil surfaces before development. Roof waters drain to water butts for garden use, and excess water from roofs, roads and paths runs to permeable paving overlying underground crushed-stone soakaways. These drain to swales, detention basins and wetlands/ponds. These measures also contribute to the provision of green space, visual amenity and wildlife on the site.

Permeable soil surfaces, swales (left) and detention basins provide sustainable urban drainage at Lamb Drove Cambridgeshire

Throughout the site, blockage free and simple flow control structures as well as overland flow paths cater for more extreme flood events. To provide a 1:100 year return period volume with an extra 20% allowance for probable climate change, peripheral ‘public open space’ was required to achieve a reasonable hierarchy of storage. Therefore recreational space in the LAP area within the site and in adjacent ‘greenway’ and golf course were designed to contain SUDS.

Capital costs were marginally lower than convention drainage. Maintenance costs are reported to be 20-25% less than conventional drainage systems. Each house has two water butts to collect rainfall from the roof, which can be used for watering gardens and other applications for which rainwater is suitable. Omission of the new storm sewer connection gives financial benefits of about £30/year/household in storm water disposal charges. The project received a commendation award at the RTPI national planning awards 2006 and has been cited in the PPS25 Practice Guide.

The driving force behind the project is the growing pressure for new housing in Cambridgeshire, with up to 50,000 new houses planned to be built by 2016. It is also a relatively low-lying county where flooding in river valleys and urban watercourses is a major concern.


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Summary of the costs of degradation

Drawing on the preceding analysis the estimated total annual costs of soil degradation in England and Wales for those items quantified in money terms (Table 13) range between £0.9 bn and £1.4 bn per year, with a central estimate of £1.2 bn per year. Estimated quantified degradation costs excluding loss of soil carbon ranges between £0.5 bn and £0.7 bn per year.

In terms of degradation, about 45% of total annual soil degradation costs are associated with loss of organic content of soils, 39% with compaction and 13% with erosion.

In terms of ecosystem services, 20% of the estimated annual costs of soil degradation are associated with loss of provisioning services linked with agricultural productivity, both reduced output and increased costs. The remaining 80% of total annual degradation costs are associated with loss of regulating services, the bulk of this (49% of all costs) linked to GHG emissions. Flood related costs (flood damage and flood risk management) account for about 19% of total costs) and water quality related costs (both drinking water and freshwater water) accounts for about 11% of costs.

It is noted that estimates of the cost of diffuse contamination of soils, soil biota loss and sealing are not available at the national scale. Current diffuse contamination and costs are thought be low, controlled by regulation. The costs of loss of soil biota loss are considered to be mainly covered by other quantified costs. The cost of urban sealing is not known at the moment.

The aforementioned quantified costs are considerably larger than those estimated in the Soil Strategy for England (£206-£315 million per year) as referred to earlier.

Table 13 Estimated total costs of soil degradation in England and Wales classified by ecosystem services and impact category

<table>
<thead>
<tr>
<th>£ million per year, 2010</th>
<th>Ecosystem Service</th>
</tr>
</thead>
<tbody>
<tr>
<td>Degradation process</td>
<td>Provisioning</td>
</tr>
<tr>
<td></td>
<td>agric prod</td>
</tr>
<tr>
<td>Erosion</td>
<td>30-50</td>
</tr>
<tr>
<td>Compaction</td>
<td>180-220</td>
</tr>
<tr>
<td>Soil organic content</td>
<td>2</td>
</tr>
<tr>
<td>Total</td>
<td>212-270</td>
</tr>
<tr>
<td>%</td>
<td>20%</td>
</tr>
</tbody>
</table>

* cost of regulation to protect soils from contamination
\* Estimates not available at national scale

Table 14 shows the distribution of soil degradation costs by soil type. Non-clay soils, particularly sandy soils, account for a proportionately large share of erosion costs relative to their areas. Compaction costs are proportionately larger on clay soils and sands. Organic matter loss is high in total on clays because of their large area, but proportionately greater on peat soils.
Table 14 Percentage distribution of estimated quantified annual costs of soil degradation for England and Wales by soil type

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Clay</th>
<th>Silt</th>
<th>Sand</th>
<th>Peat</th>
</tr>
</thead>
<tbody>
<tr>
<td>% of total area</td>
<td>59%</td>
<td>20%</td>
<td>12%</td>
<td>9%</td>
</tr>
<tr>
<td>Costs (£ '000)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Erosion
- On-site: 39,874 (20%)
- Off-site: 81,430 (19%)
- Total: 121,304 (20%)

Compaction
- On-site: 203,691 (74%)
- Off-site: 266,889 (70%)
- Total: 470,579 (72%)

Organic matter loss
- On-site: 3,507 (37%)
- Off-site: 566,124 (37%)
- Total: 569,631 (37%)

Table 15 shows the distribution of degradation costs by land use. It is clear that erosion and compaction degradation costs are positively correlated with the intensity of farming: for example arable farming accounts for 77% and 47% of total annual erosion and compaction costs respectively on 32% of the total area. Organic matter loss is proportionately greater on grassland, including unimproved grassland, reflecting the use of peat soils.

Table 15 Percentage distribution of quantified annual quantified costs of soil degradation in England and Wales by land use

<table>
<thead>
<tr>
<th>Land use</th>
<th>Erosion On-site</th>
<th>Off-site</th>
<th>Total</th>
<th>Compaction On-site</th>
<th>Off-site</th>
<th>Total</th>
<th>Organic matter loss On-site</th>
<th>Off-site</th>
<th>Total</th>
<th>% of total area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>0%</td>
<td>22%</td>
<td>12%</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>11%</td>
</tr>
<tr>
<td>Horticulture</td>
<td>6%</td>
<td>3%</td>
<td>4%</td>
<td>10%</td>
<td>0%</td>
<td>5%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>&lt;1%</td>
</tr>
<tr>
<td>Arable intensive</td>
<td>27%</td>
<td>25%</td>
<td>26%</td>
<td>17%</td>
<td>3%</td>
<td>9%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>3%</td>
</tr>
<tr>
<td>Arable extensive</td>
<td>48%</td>
<td>52%</td>
<td>51%</td>
<td>49%</td>
<td>29%</td>
<td>38%</td>
<td>13%</td>
<td>13%</td>
<td>13%</td>
<td>29%</td>
</tr>
<tr>
<td>Grassland improved</td>
<td>10%</td>
<td>11%</td>
<td>11%</td>
<td>20%</td>
<td>29%</td>
<td>25%</td>
<td>13%</td>
<td>13%</td>
<td>13%</td>
<td>25%</td>
</tr>
<tr>
<td>Grassland unimproved</td>
<td>7%</td>
<td>7%</td>
<td>7%</td>
<td>4%</td>
<td>7%</td>
<td>6%</td>
<td>33%</td>
<td>33%</td>
<td>33%</td>
<td>11%</td>
</tr>
<tr>
<td>Rough grassland</td>
<td>1%</td>
<td>1%</td>
<td>1%</td>
<td>0%</td>
<td>3%</td>
<td>2%</td>
<td>11%</td>
<td>11%</td>
<td>11%</td>
<td>5%</td>
</tr>
<tr>
<td>Forestry</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>0%</td>
<td>7%</td>
<td>7%</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td>Woodland</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>5%</td>
<td>3%</td>
<td>4%</td>
<td>4%</td>
<td>4%</td>
<td>8%</td>
</tr>
<tr>
<td>Wildscape</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>1%</td>
<td>1%</td>
<td>16%</td>
<td>16%</td>
<td>16%</td>
<td>5%</td>
</tr>
</tbody>
</table>

Uncertainties, gaps and recommendations

This assessment of the costs of soil degradation largely confirms the difficulties, evident in previous reviews 98, of deriving complete and reliable estimates of the benefits provided by soils and how these change according to soil condition. There are three aspects to this challenge (i) ‘identifying’ biophysical relationships between soil properties, soil functions and ‘performance’ of soils in particular applications (ii) ‘valuing’ the diverse range of market and non market benefits and costs attributable to soils in different applications and (iii) assessing the ‘dynamics’ of soil properties, especially under conditions of climate change, as these affect changes in the supply and value of services.

The ecosystems approach adopted provides a systematic framework for the identification and valuation of soil services, although in many respects it confirms that knowledge is insufficient complete to allow a full assessment. Furthermore, although some information is available for particular degradation processes on specific sites, it is difficult to aggregate this at the regional and national scale to support policy. A number of key gaps and uncertainties can be identified.

There is considerable information and knowledge pertaining to soils that has been developed over time, much of it to support land suitability assessments, associated mainly with agriculture. While this remains a key aspect of soil management, the ecosystems service perspective requires that soil science and management adopt a broader remit to include the wide range of soils functions as they support regulating and cultural services as well as provisioning services.

The soil science literature shows that, given the dominant purpose in the past, there has been a focus on mainly physical and chemical properties of soils, relatively limited focus on biological processes, and more limited interpretation of soil science for economic appraisal and policy purposes. It is evident that much research stops with observations of biophysical relations, such as the measurement of soil compaction, without interpreting this for soil functions and outcomes, such as yields or runoff generation. In this respect the links into impacts, policy and practice are not beneficially developed as much as they could be.

One key issue in this respect is the definition of soil degradation risk. While the incidence or probability of soil degradation processes, such as erosion or compaction, has been a focus of research, there has been relatively limited assessment of economic and other impacts. For this reason, it is difficult to undertake an outcome/damage based ‘risk’ assessment of soil degradation, in the way, for example, that might be undertaken for flood risk where the probability and consequences of an event are distinguished and combined. The approach adopted here attempted to do this, within the limits of available data.

An attempt was made here to link degradation processes, indicators of soil quality and ecosystem services. Examples include (i) erosion, soil depth and crop yield and (ii) compaction, packing density and runoff. It proved difficult to confidently predict these process/indicator/service relationships, yet this is clearly the way forward if the ecosystems approach is to be comprehensively applied. Selecting the units of service delivery that relate the pertinent indicator of soil quality (eg soil organic content), to service (eg yield), and understanding how changes in the former affect changes in the latter is central to this process. A better understanding of the relation between soil qualities and service provision is also needed to inform ‘safe’ or ‘target’ indicator levels beyond which ecosystems services might be undesirably or irreversibly compromised. Linked to this, there is clearly a need to better understand how the use of soils drives the relationship between the stock of soil resources, defined in terms of soil quantities and qualities, and the flow of soil-based services. Pressures of development and climate change make this a priority.

The ecosystems approach emphasises how degradation can reduce the capacity of the stock of soil ‘capital’ to provide soil services now and into the future. Over utilisation of soils beyond their natural ability to maintain or reinstate their inherent properties leads to degradation of stocks and service flows. In some cases this can be corrected by measures to prevent or minimise degradation, in others by substituting lost soil properties with man-made inputs such as artificial fertiliser. These interventions can be costly.

While these stock flow relationships were explored here, further data and knowledge are required to adequately understand the complex relationships between soil stocks and service flows for major soilscapes, especially under alternative management scenarios. Associated with this, as referred to earlier, is the issue of critical stocks of soil capital, of thresholds and of non linear effects, whereby degradation leads to non marginal, step changes in both stocks and flows. Here, uncertainty-based safe minimum standards, set within a strong regulatory regimes, are appropriate. This is currently the case for potential sources of diffuse contamination of soils. It is recommended that critical threshold values are explored for other degradation processes, such as compaction, soil organic content and soil sealing for major soilscapes,

The analysis here clearly shows that there is considerable spatial variability not only the processes of soil degradation but also in their consequences. The soilscape approach explicitly considers spatial distribution of causes and effects. The associated question of scale effects is relatively unresearched as most soil degradation has been studied at the individual plot scale. As a consequence, the offsite impacts of processes on individual plots (such as compaction causing runoff) become important at the larger scale, whether catchment, regional, national or global. An appreciation of spatial variation and scale are critical to the assessment of the consequences of soil degradation, especially in the context of diverse ecosystems services. The recent initiatives on Demonstration Test Catchments99 and Catchment Sensitive Farming100 will yield useful information in this respect.

Variation in time is also important, especially as degradation processes and effects can be cumulative over time. There is incomplete understanding of cumulative rates of degradation associated with for example soil organic matter loss, or the cumulative effects of compaction on some arable soils in the absence of treatment. This aspect, to develop a better understanding of the relationship between changing soil stocks and diverse service flows over time, is essential for a strategic approach to the management of soil resources. It is recommended that this is a priority for future research.

99 http://www.lwec.org.uk/activities/demonstration-test-catchments
100 http://www.naturalengland.org.uk/ourwork/farming/csf/default.aspx
The degradation processes here have been considered separately but it is noted that there are many joint, interacting and overlapping, effects and outcomes. For example, soil compaction on hillslope can exacerbate the probability of erosion. It was reported that loss of organic content and soil biota are closely integrated with other degradation processes and effects. Future soil research should explore the correlations, tradeoffs and synergies amongst soil degradation (and amelioration) processes and their economic and other effects, particularly where these are cumulative and integrating.

The assessment at the national scale has been developed here for three degradation processes, namely: erosion, compaction and soil organic matter. Although there is some site specific, local case material, information to support national estimates for soil biota loss, soil diffuse contamination and soil sealing is not readily available. For the most part the links between degradation processes, units of service delivery and values of services are difficult to develop with existing information and without extensive field work (that was not possible here). It is recommended however a number of cases could be developed to inform a general approach to economic assessment generating values that could be ‘transferred’ for use elsewhere.

It is also apparent that the links between soil quality and ecosystem services are best developed for provisioning (mainly agricultural production) and regulating services (water quality, GHG emissions and flooding). Information to support the contribution of soils to supporting cultural services, such as landscape, biodiversity, recreation and heritage is less developed. The condition of soils can make a difference to the quality of important and highly valued habitats. They are important in the preservation of archaeological artefacts. They affect the condition of footpaths that provide access to the countryside, and the visual appearance of landscapes. The extent to which this affects the value of services has not been explored to any great extent to date, and has not been developed here. It is recommended that the cultural dimension of soils are assessed to provide a more complete assessment of soil value.

The analysis has identified a number of gaps and uncertainties in the valuation of service flows that are both specific to soils and generic to the valuation of non market ecosystem services as a whole. The main non market impacts of soil degradation appear to relate to flood risks, water quality impacts and GHG emissions, all of which are subject to uncertainties in valuation. Flood risk and water quality impacts vary considerably according to the sensitivity of local ‘receptors’, while GHG valuation rests on the social price of carbon (based here on the cost of CO$_2$ abatement). It is noted that market prices used to value soil service are also uncertain, for example for agricultural inputs and products. For this reason it is important to separate as far as possible biophysical and pricing assumptions, and to generate a range of values to reflect uncertainty.

The analysis here considers degradation in the context of major soilscape options. They provide the context in which degradation is assumed to occur and the notion of a ‘without-degradation’ counterfactual against which degradation costs can be assessed. In practical terms, some soilscape inevitably result in degradation, such as arable farming on peatlands. Here changing land use to extensive wetgrassland could halt degradation but a very different set of service flows would result. Consideration of these soilscape options is beyond the current brief but could be justified for key areas of vulnerability. Furthermore, within given soilscape, a range of locally suitable measures, some currently in operation, can be used to control degradation, albeit at a cost. The analysis here has focussed more on the costs of degradation than the cost of prevention, taking care to avoid double counting. It would be beneficial to assess the cost effectiveness of alternative measures for managing major degradation risks according to major soilscape.

**Conclusions and recommendations**

The assessment here has explored the total economic costs of soil degradation using an analytical framework based on spatially differentiated soilscape and ecosystem services.

The total quantified costs of soil degradation in England and Wales are estimated at between £0.9 bn and £1.2 bn per year. Compaction and loss of soil organic content account for 39% and 45% respectively of quantified annual costs. Silts and sands account 67% of total estimated erosion costs, and clays and sands for 91% of compaction costs. Almost 80% of total quantified costs occur offsite.

In terms of soilscape, arable farming accounts for over 70% of erosion and compaction related costs. Grassland farms account for about 57% of the estimated costs of the loss of organic content.

In terms of ecosystem services, 20% of the estimated annual quantified costs of soil degradation are associated with loss of provisioning services linked with agricultural production. The remaining 80% of total annual degradation costs are associated with loss of regulating services, with 49% of all costs linked to GHG emissions. Flood related costs (flood damage and flood risk management) account for about 19% of total costs and water quality related costs (both drinking water and freshwater water) account for about 11% of costs. Although, the contribution of soils to cultural services is considered to be locally and regionally important, and potentially significant at the national
scale, this remain largely unquantified at this stage. The costs of soil degradation in the urban environment is also underidentified.

From a policy perspective, set in the context of the EU’s Thematic Strategy for Soil Protection Strategy and UK national soil strategies, there is an economic argument to focus on the avoidance of soil compaction and erosion on intensively farmed soils and the maintenance of organic content of soils generally. Indeed, protecting the carbon content of soils would probably embrace all aspects of soil quality. In an urban context, the avoidance of flood risk associated with soil sealing should be a focus.

The analysis here confirms the complexity of the causes, processes and impacts of soil degradation that makes assessment difficult. In particular soil degradation is closely linked to the way land and soils are used. ‘On-site’ users of soils may not be aware of the long term effects of degradation on the benefits they themselves obtain from land and its soils. More particularly, they are often unaware of the immediate and long term consequences of soil degradation that are felt indirectly ‘offsite’, often some distance from where degradation occurs.

The assessment here, incomplete as it is, can help to inform a better understanding of the beneficial functions of soils and the costs of soil degradation, including changes in policies and practices that can lead to their more sustainable use.
References to published material

9. This section should be used to record links (hypertext links where possible) or references to other published material generated by, or relating to this project.


Defra (2007) An introductory guide to valuing ecosystem services. 68pp


Defra Project BD2304 (2007). Scoping study to assess soil compaction affecting upland and lowland grassland in England and Wales


Discussions with LGA engineers in Cambridgeshire and Buckinghamshire was not able to separate costs for soil erosion related


Environment Agency, 2009b Flooding in Wales, Environment Agency, Cardiff


HMT (2003), The Green Book. Her Majesty's Treasury, London for a discussion on the choice of discount rates for public investment appraisal. High discount rates tend to encourage relatively rapid depletion of soils whereas low discount rates tend to encourage soil conservation strategies in order to secure continued future benefits from soils.


KeySoil: http://www.keyssoil.com/


LWEC: http://www.lwec.org.uk/activities/demonstration-test-catchments


NATMAP: http://www.landis.org.uk/data/natmap.cfm


Palmer RC. 2004. Soil structural conditions in the axe and char catchments during march 2004. NSRI research report No. YSR 9127V for FWAG (Devon) and Environment Agency, 36p


Palmer RC. 2004. Soil structural conditions in the axe and char catchments during march 2004. NSRI research report No. YSR 9127V for FWAG (Devon) and Environment Agency, 36p


Probability of occurrence here is taken to be a measure of the magnitude/intensity of a degradation process, which combines aspects of the relative incidence across a soilscape and the intensity of the degradation process where it occurs. It was hoped to separate out probabilities and intensity, for example by constructing an estimates of mean and variance of degradation processes within a landscape. This was not possible with the information available, although it might be possible using a modelling approach.


Silsoe Whole Farm Model: http://www.cranfield.ac.uk/sas/naturalresources/research/projects/silsoewholefarmmodel.html


SP1101: Comparison of soil carbon changes across England and Wales estimated in the Countryside Survey and the National Soil Inventory


UK NEA (2011) UK National Ecosystem Assessment: Synthesis of the Key Findings. UNEP-WCMC, Cambridge
