SEPA
Scottish Environment Protection Agency

COMMISSIONED REPORT

SOCIO-ECONOMIC DATA ON SCOTTISH SOILS – COLLECTION AND DEVELOPMENT

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COMMISSIONED REPORT

Summary

Socio-economic data on Scottish soils – collection and development.

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Background

There is increasing awareness that socio-economic information will be required to support the development and implementation of effective strategies to protect and manage our soil resources into the future. Socio-economic data on Scottish soils are not widely available and it is acknowledged that there is a need to improve both the quantity and quality of this information for a variety of purposes, including the forthcoming publication of the State of Scotland's Soils Report coordinated by SEPA along with a wide range of partners[1]

Main findings

- This report provides a comprehensive overview of the socio-economic impacts associated with each soil pressure. The large number of impact categories and the variety of affected soil functions and ecosystem services reflects the integrative and essential role that soil plays in sustaining human activities and ecosystems.
- The assessment of impacts illustrates that large knowledge gaps exist in appraising the socio-economic impacts of soil pressures, in part due to the difficulties in relating economic impacts specifically to soil.
- The data gaps made it difficult to compare the magnitude of socio-economic impacts *between* pressures, but also to evaluate the relative impacts of categories for *each* pressure. This contributes to large uncertainties regarding the magnitude of impacts for many pressures.
- The assessment was also complicated by a lack of processed information on the spatial distribution and nature of biophysical impacts across Scotland.
- Suggestions are given for reducing uncertainties using available information, the impact categories identified in the report, and screening according to relevant biophysical and related socio-economic indicators for Scotland. Because of the huge scope of such a project, the approach could be tested for single selected pressures first before being extended to all pressures.
- The report includes lists of examples that make reference to real issues in Scotland. These lists could be extended, translating the generic impact categories into real-world examples and detailing the examples with information on, for example, the state of knowledge, the spatial distribution and magnitude of biophysical impacts, the actors involved and the availability of related information on costs and benefits.
- Specific management or policy options impacting on soil, and soil functions, would be a useful approach to data collection from a socio-economic point of view. It would

[1] The Scottish Government, the Macaulay Institute, Scottish Natural Heritage, the Scottish Agricultural College, the Forestry Commission, Historic Scotland, Scottish Crop Research Institute, the British Geological Survey and the Centre for Ecology and Hydrology.

be necessary to collect data on alternative management options aimed at reducing soil degradation to ultimately prioritise them according to social desirability taking into account all private and social costs and benefits associated with these options.

- Policy or management options may be associated with several pressures at the same time. Due to interactions between soil pressures, summing the total cost estimates of all soil threats would result in an overestimate of the total cost of soil degradation for Scotland due to double counting. Linkages between pressures should be specifically addressed from a socio-economic perspective in future work. Such work could also identify positive and negative feedback loops between pressures.
- A more detailed investigation of socio-economic impacts associated with one of the pressures, soil erosion, highlighted a wide range of estimates for the different cost categories drawn from a range of countries over a number of years. These estimates are often context dependent and this reduces the confidence with which they can be transferred to Scotland beyond giving a high level estimate of the potential range of costs.
- We suggest that soil erosion costs estimates for Scotland could be obtained by a case study approach in small number of representative catchments where there is an identified risk of soil erosion. Social cost estimates may be obtainable from public bodies (e.g. Scottish Water, local authorities); water quality impacts, including non-use values, could be obtained by adjusting values from existing stated preference studies on water quality to account for the impact of soil erosion (e.g. suspended solids).

Table of Contents **Page**

List of Tables **Page**

List of Figures **Page**

INTRODUCTION

1.1 Introduction

There is increasing awareness that socio-economic information will be required to support the development and implementation of effective strategies to protect and manage our soil resources into the future. Socio-economic data on Scottish soils are not widely available and it is acknowledged that there is a need to improve both the quantity and quality of this information for a variety of purposes, including the forthcoming publication of the State of Scotland's Soils Report coordinated by SEPA along with a wide range of partners.[2]

1.2 Aims and Objectives

The primary aims of the project were to provide socio-economic data to improve the understanding of the importance of Scottish soils and to identify ready-to-use socio-economic data that can be included in the State of Scotland's Soils report. As this was the first time that such work was carried out at this scale, the project also aimed to provide recommendations for improving the quantity and quality of such data for future use.

The following objectives were agreed with the steering group at the project inception to address requirements for the State of Scotland's Soils report:

1. Soil pressures. This set out the pressures being reviewed within the State of Scotland's Soils Report and set the context for the following objectives.

2. Assessment of (socio)-economic impacts. This focussed on economic impacts associated with each pressure. Methodological issues concerning data needs to quantify impacts or interactions and overlap between pressures were discussed. Generate overviews for soil pressures, which included the following information:
    a. State (land-use, coverage, etc)
    b. Drivers of change
    c. Trends of change
    d. Impacts on soil/ecosystem functions
    e. Economic impacts and ecosystem services associated with these

3. For one pressure identified in agreement with the steering group, a thorough review of the economic data available was conducted. As the timeframe did not allow for the collection of primary data for Scotland this was based on studies from outside Scotland such as the EU report prepared by Ecologic (Görlach *et al*., 2004) and the ADAS study commissioned by Defra (ADAS, 2006) and the Soil Strategy for England Supporting Evidence Paper (Defra, 2009).

4. For the selected pressure, we assessed the transferability of existing data and approaches from other studies to the Scottish situation. This was assessed mainly qualitatively on the basis of site (ecosystem, land use) similarity and other study specific criteria such as socio-economic characteristics (e.g. population, incomes). A sensitivity analysis was not possible at this stage. This approach provided an appropriate way forward within the short timescale of this project.

5. A discussion on knowledge gaps, data needs and recommendations for further action.

[2] The Scottish Government, the Macaulay Institute, Scottish Natural Heritage, the Scottish Agricultural College, the Forestry Commission, Historic Scotland, Scottish Crop Research Institute, the British Geological Survey and the Centre for Ecology and Hydrology.

6. Presentation of the key results of the study to the SEPA project steering group, if required.

7. Reporting.
   a. Draft report. The draft version of this report will be submitted electronically to the Project Steering Group Board for information and comments.
   b. Final report. The final version report will include amendments to reflect comments received. The report will be submitted electronically and requirements for printed copies agreed at the project inception meeting.

These objectives will improve the position of SEPA in terms of understanding the state of and future needs for socio-economic research on soils and soil-related ecosystem services. Specific benefits include improving the capacity SEPA to understand which socio-economic data on soils are available and key principles to be included in socio-economic data development.

SOIL PRESSURES

2.1 Introduction

The Scottish Soil Framework (The Scottish Government, 2009) states that "Scotland's soils perform a large number of economic and environmental functions". Many industries, including farming and food production, forestry and tourism, depend on the sustainable use of soils. Soil management also plays an important role in sustainable flood management." Scottish soils are generally of good quality. However, the vital functions performed by soils are under constant and increasing threat from a range of soil pressures. Towers et al. (2006) examined and ranked a range of pressures ("threats") to Scottish soils and concluded that climate change and the loss of soil organic matter posed the most significant threats to Scottish soils and their functions (Table 1). The forthcoming report on the State of Scotland's Soils by SEPA is in the process of drafting chapters on the drivers, environmental impacts, status and trends for a series of soil pressures.

These pressures include:

- Loss of Soil organic matter
- Soil Sealing
- Contamination
  - Atmospheric deposition
  - Metals
  - Persistent organic pollutants
  - Pathogens
- Degradation of soil biodiversity
- Erosion and landslides
- Soil compaction
- Emerging issues
  - Biochar
  - Nanomaterials in soils
  - New contaminants (including asbestos)

The assessments of soil pressures, to date, primarily reflect the biophysical interpretation of the threats to, and pressures on, soil functions. It is now timely to evaluate how these assessments can be linked to or translated into information useful to determine the ultimate costs of soil pressures to the delivery and maintenance of ecosystems services within Scotland.

Table 1 *Soil pressures: trends in, status of, impact on, extent of, uncertainty in and reversibility of with respect to the functions of soil in Scotland (adapted from Towers et al., 2006)*

Soil Functions, as defined in the Scottish Soil Framework		**Providing the basis for food and other biomass production**					**Regulating water flow and quality**					**Storing carbon and maintaining the balance of gases in the air**					**Providing valued habitats and sustaining biodiversity**					**Providing a platform for buildings and roads**					**Providing raw materials**					**Protection of cultural and archaeological heritage**				
Pressures on soil	Trends	Status	Impact	Extent	Uncertainty	Reversibility	Status	Impact	Extent	Uncertainty	Reversibility	Status	Impact	Extent	Uncertainty	Reversibility	Status	Impact	Extent	Uncertainty	Reversibility	Status	Impact	Extent	Uncertainty	Reversibility	Status	Impact	Extent	Uncertainty	Reversibility	Status	Impact	Extent	Uncertainty	Reversibility
Loss of soil organic matter	0	N	2	2	2	1	Y	3	3	2	3	N	3	3	2	2	?	3	2	2	3	r	0	0	0	0	?	2	1	2	3	?	2	1	2	3
Soil sealing	↑	?	3	1	3	3	?	3	1	3	2	?	3	2	3	3	Y	3	1	2	3	Y	0	0	0	0	?	3	1	1	3	?	3	1	2	3
Contamination (atmospheric deposition)	↓	Y	1	2	1	3	Y	2	3	1	3	?	3	3	2	2	Y	2	3	2	3	r	0	0	0	0	?	0	0	0	0	?	2	1	3	0
Contamination (metals)	↓	Y	2	2	2	2	Y	2	2	2	3	?	2	1	2	2	Y	2	2	2	3	r	0	0	0	0	?	0	0	0	0	?	0	0	3	0
Contamination (POPs)	↓	N	1	2	1	1	Y	2	2	2	2	?	2	1	2	2	?	2	2	2	2	r	0	0	0	0	?	0	0	0	0	?	0	0	0	0
Loss of biodiversity	↑	?	2	2	3	2	?	2	3	3	2	?	3	3	3	2	Y	3	3	3	2	r	0	0	0	0	?	?	?	?	?	?	?	?	?	?
Erosion / landslides	↑	?	2	1	2	1	?	3	1	2	2	?	3	1	2	2	?	2	2	2	2	?	2	1	3	2	?	1	1	2	2	?	3	1	1	3
Soil compaction	↑	Y	2	1	2	1	?	2	1	1	1	?	2	1	1	1	?	2	1	2	1	?	0	0	0	0	?	0	0	0	0	?	1	1	2	2

Table 1 – Description of terms and scoring system for scoring of pressures:
Trends over medium term (20-25 years). This describes whether a pressure is increasing or decreasing in magnitude or is relatively static based on published evidence or anecdotal information (e.g. feedback from land managers).

- 0 = no change;
- ↑ = increase in pressure;
- ↓ = decrease in pressure

Status. This describes whether the influence of a pressure has reached a point of potential harm to soils.

- Y = known exceedance of thresholds ;
- N = no exceedance yet reported;
- ? = not known as no thresholds yet established;
- r = not relevant

Impact over medium term (20-25 years). This provides an assessment of the consequences of each pressure;

- 0 = none known:
- 1 = Low, unlikely to have any significant impact on that function;
- 2 = Moderate impacts on the function are significant, but not threatening the operation of the function itself;
- 3 = High, likely to lead to serious impairment or the loss of that function

Extent across Scotland. An assessment of the spatial resolution at which each pressure impacts:

- 0 = Very limited extent or confined to specific environments;
- 1 = Local, confined to a limited number of soils or environments or occurring as low frequency events;
- 2 = Regional impacts confined to one major region or soil environment within Scotland (e.g. arable soils, upland areas);
- 3 = National impacts on almost all soils in Scotland

Level of uncertainty An appraisal of our understanding of the pressure and the evidence base and data to support this.

- 1 = Low, pressure is well characterised, causal factors well understood and quantified where possible, good quantitative data on the soils affected;
- 2 = Moderate, causal factors not fully understood, some data gaps on soils affected (e.g. evidence from limited research studies or qualitative information rather than national data);
- 3= High, poor understanding of the causal factors with no quantification of the effects of these, few data on which to assess current status of soils affected.
- ? = Not known

Reversibility of impacts. An assessment of the extent to which the effects of the pressure are naturally attenuated, can be mitigated, remediated or reversed:

- 1 = High, impacts can be easily reversed by management practices or natural attenuation, reversal possible within a season;
- 2 = Moderate, can be reversed but only by significant changes to management practices, technical intervention or by new guidelines or policy, reversal possible within a few years;
- 3 = Low, effectively irreversible; no economic or technical/management solution, effects can only be reversed by major changes in policy at a national or international level and/or are likely to take many decades
- ? = not known

ASSESSMENT OF SOCIO-ECONOMIC IMPACTS

3.1 Introduction

Soils perform several functions that are essential to (human) life on earth. They provide a flow of services (i) for the development and maintenance of the functionality of the soil system itself, (ii) for ecosystems and (iii) for human uses. Although (i) or (ii) are of great importance and underpin the resilience of soil and ecosystems, this report focuses on the (socio-) economic impacts of soil degradation for human uses. While an assessment of the capital stock of soil in Scotland would be useful to evaluate the sustainability of soil management, a focus on the flow of services provided by soils and their value revealed by changes in terms of soil degradation (or improvement) is more informative for an impact assessment or policy analysis. The value of the stock of Scotland's soils would need to be estimated by quantifying the discounted sum of future flows of benefits, which is a more complex undertaking than identifying a single year's flow.

Below, we describe potential economic impacts that are associated with soil degradation. Soil degradation is understood as a negative change in the capacity of soil to provide services demanded by humans. The impacts relate to the six pressures to soil that have been identified to be relevant for Scotland in previous work (Towers *et al*., 2006) and are currently under review for the SEPA State of Scotland's Soils Report. The measurement or valuation of economic impacts in monetary terms can be done either in cost or in benefit terms, depending on the methods used.

3.2 Economic valuation of soil degradation – Theory and available methods

Economic costs arise if a change from the status quo (reflecting current use and management) results in a decline of soil to provide ecosystem services valued by humans (e.g., compaction resulting in increased N_2O emissions from wetter soils). Economic benefits arise from either slowing down the decline or improving the service providing capacity of soil relative to the counterfactual[3]. They reflect the costs of inaction and the benefits of (counter)acting against (further) soil degradation (e.g., field buffers to counter negative impacts of soil erosion on water bodies) or maintaining the flow of services even though soil degradation continues (e.g. fertiliser use to counter falling yields). Costs of inaction need not be equal to the benefits of action, and there are important differences in the economic methods that can be used to value costs and benefits in monetary terms as willingness-to-pay (WTP) or willingness-to-accept[4].

Methods to value soil endpoints can draw on a range of approaches developed in environmental economics, specifically market price methods, stated and revealed preferences and benefits transfer. In essence, market price approaches use existing observable (sometimes corrected) market prices to represent the costs of soil degradation or loss[5] in terms of the necessary replacement costs for soil nutrients/structure (to avoid the costs of reduced yields) or the replacement costs or defensive expenditures needed to remediate damage done when soil impacts are felt off site (for example in case of increased flood risk as a result of compacted/sealed soil or impact of soil erosion on water quality). In the absence of direct market values or cost data, more sophisticated approaches (e.g.

[3] The counterfactual refers to the alternative scenario to that being valued. This may reflect the current situation (status quo); current trends; or no provision of a good or service. Valuations can only be made for changes relative to a defined counterfactual.
[4] Willingness-to-pay is the maximum amount in monetary terms that an individual would be willing to pay in exchange for consuming a good, willingness-to-accept is the amount an individual is willing to accept in exchange for forgoing or abandoning the consumption of a good.
[5] Conversely the benefits of conservation

hedonic pricing) can use market data or surrogate prices (e.g. for land transactions) to infer the value of soils, i.e. preferences are "revealed" by observing behaviour. Finally, in the absence of any price "behavioural trail", hypothetical markets can be employed to measure "stated preferences" by eliciting values for changes in soil quality (e.g. contingent valuation or choice experiments/modelling). In essence, these methods elicit preferences for changes in environmental conditions directly from a sample of respondents. Methods that directly or indirectly rely on market prices (e.g. production function, replacement costs/defensive expenditures, hedonic pricing, travel cost approaches) provide estimates of minimum WTP for a change in services related to soil and are therefore lower bound estimates of 'true' WTP. In contrast, stated preference methods produce estimates of people's maximum WTP[6] for a change, which is an upper bound estimate. The choice of method employed also influences the nature of the values being identified. Market and revealed preference values can only reflect direct and indirect consumptive values (i.e. use values) whereas stated preference approaches offer the potential to estimate both use and non-use (option, bequest and existence) values.

Benefit transfer cannot be regarded as a valuation method per se, but it is a quick and inexpensive alternative to original value studies in which existing value data are transferred. Nevertheless, policy applications and the accuracy of the value estimates obtained through benefit transfer often remains in doubt (Piper and Martin, 2001; Ecologic, 2005). Too often transferred values are indiscriminately reported in policy/regulatory appraisal documents without adjustment or only including a slight modification to account for income differences between locations (Parsons and Kealy, 1994). Although there have been recent methodological advances regarding benefit transfer, doubts on the accuracy of transferred values remain in the scientific domain. Eventually, whether or not a certain level of accuracy is acceptable and which degree of error can be tolerated against the cost and time of conducting original valuation studies is subject to decision makers who want to use the resultant information.

3.3 On-site/off site effects

A distinction between off-site and on-site impacts is useful for several reasons. First, it reflects where impacts in terms of costs or benefits arise spatially. On-site costs/benefits are related to impacts that occur on or within the land itself, whereas off-site impacts are spatially disconnected from the land that is subject to a change driven by a soil threat. Secondly, on-site costs/benefits are incurred by the soil user or landowner, while off-site costs/benefits are borne by society. Generally, on-site impacts are more immediate than off-site impacts, which can occur with temporal delay. Additionally, it is more difficult to exactly determine how soil degradation contributed to off-site costs/benefits. For example, soil erosion may not be the sole driver of eutrophication of water bodies. Due to diffuse sources, it is often also difficult to identify the exact source of off-site impacts that occur far from its origin. In economic terms, off-site impacts are externalities of private land-based activities to society. It has frequently been found in the literature (see Görlach *et al*., 2004) that off-site economic impacts can exceed on-site impacts, in many cases by some margin.

3.4 Economic impact categories

Following Görlach *et al*. (2004), we distinguish 5 impact categories (Figure 1):

[6] Maximum willingness to pay is the amount of money an individual would give up in exchange for improvements, e.g. in environmental conditions, to remain on the same utility level as before the exchange took place. In other words, it is the amount of money an individual would part with to be as well off after a change (in environmental conditions) than before.

- The **on-site (private) costs (PC)** associated with a loss or decline of soil's capacity to provide ecosystem services. On-site private costs have a direct impact on the landowners or soil users. For example, they affect profit margins of land-based businesses due to a decline in productivity of land as a result of soil degradation processes.

- The **on-site (private) costs of mitigation (MC)** arise from efforts to (partially) restore the capacity of soil to provide ecosystem services.

- **Costs of defensive measures (DC)** to prevent and reduce negative off-site effects. Examples are measures that prevent eroded soil from leaving land boundaries and entering water bodies. Whether costs of defensive measures are borne by private soil users/owners or society depends in practice on the degree to which society expects (via legislation and regulation) private landowners to minimise negative externalities that arise from their activities.

- The **off-site (social) costs (SC)** of soil degradation are the costs that arise from negative externalities. Examples are reduced buffering capacity of soils to retain pollutants and prevent them from entering surface or ground water; or benefits forgone from reduced capacity of soil to sequester carbon.

- Under **non-use costs (NC)** we summarise all other costs that are not related to direct or indirect use of soil. This includes existence values, the benefit people receive from just knowing that something (e.g., wildlife) exists even though they never see it, and values that arise from bequest motives i.e. knowledge of maintaining soil's capacity for future generations. Distinctions between NC and SC are not always clear-cut, for example for impacts on landscape amenity.

Because pressures are more related to soil degradation than improvements then, for pragmatic reasons, most impacts will be described as costs. However, we would like to emphasise that pressures may in some cases (e.g. climate change and improvement in land capability for agriculture) also yield benefits (i.e. change that is perceived as an improvement compared to the current situation by some agents).

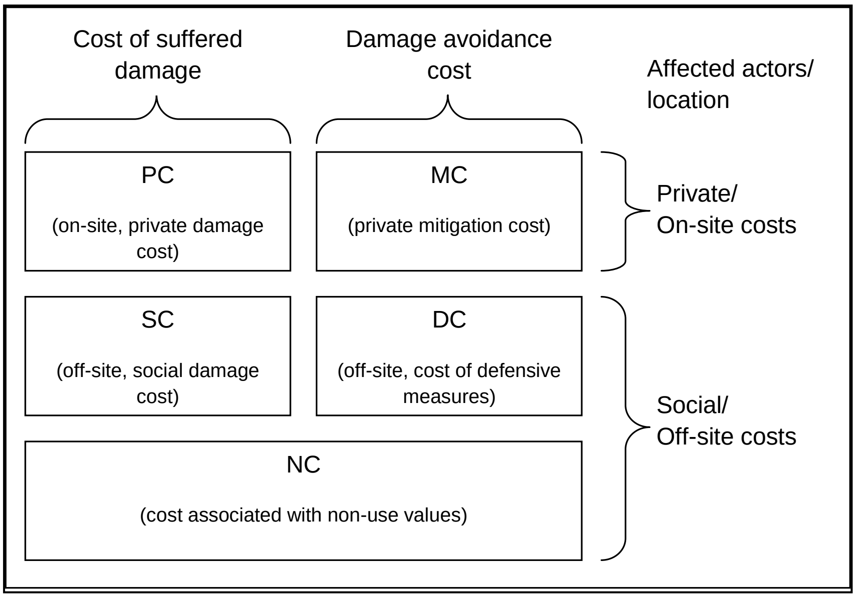

Fig. 1 *Overview of different economic impact categories (adopted from Görlach et al., 2004)*

3.5 Ecosystem services

The ecosystem services approach describes a framework that defines the services provided by natural ecosystems. A number of categories were developed (see for example de Groot *et al.*, 2002), although these have not been formalised. One of the most commonly accepted categorisations is that adopted by the Millennium Ecosystem Assessment (MEA, 2005) and is illustrated with examples in Table 2. The four broad categories of ecosystem services (provisioning, regulating, cultural and supporting services) cover a wide range of services that provide either direct or indirect benefits to humans. The nature of these services means that a range of valuation approaches can be adopted to determine the benefits that humans derive from them. The utility of the ecosystem services approach lies in its consideration of the benefits provided by the environment. A complication of the approach is that it considers the outcomes from ecosystem functioning, which result from combinations of, and interactions between, different environmental media (e.g. soil, air, water). Each environmental media will contribute to a range of different services, each to a greater or lesser extent. Therefore what is an intuitive framework in terms of outcomes masks underlying complexities, which presents challenges in terms of both physical measurement and economic assessment.

The application of the ecosystem services approach to soils presents some problems in that soils provide supporting services across a broad range of environmental media. Non-degraded soils are necessary for the provision of food, fibre and fuel. Soils also play an important underpinning role in the provision of several regulating, cultural and supporting services. Consequently care must be taken in defining the ecosystem services attributable to soils. If one is combining estimates for these services across a range of environmental media, particular care must be taken to avoid double counting. Double counting occurs when costs/benefits or components of their value are accounted for more than once in economic impact assessments. Hence, the danger of double counting is particularly high if costs/benefits cannot be clearly separated or treated independently from each other, for example for separately accounting for, and subsequently adding up, soil impacts and water impacts of soil and water conservation measures. Double counting can arise from the nature of the cost or benefit estimates used where different WTP values cover a range of overlapping impact categories. Further it may be difficult to make a reasonable apportionment of the value of an underpinning role to soils, e.g. the contribution of soils to landscape values.

Where possible, we aim to relate relevant ecosystem services to the economic impact category in Sections 4.2 to 4.7. The list of key ecosystem services related to soil in Table 3 is not exhaustive and represents only a subset of the wide range of ecosystem services illustrated in Table 2. Hence, we could not assign ecosystem service counterparts to all economic impact categories. Nonetheless, relating impact categories to ecosystem services provides a good overview of the range of ecosystem services affected by the pressures. Generally system resilience is strongly related to supporting services. It has a large primary value[7] component and is not directly linked or related to end-products used, enjoyed or consumed by humans (Banzhaf and Boyd, 2005), and economic valuation of these supporting services (in particular for marginal changes) are not advised for most cases. It is nonetheless important to understand how supporting services underpin the provision of other services and end-products consumed by humans.

[7] "Primary value" or "glue value" is not associated with use, but beyond it's value to humans (Turner *et al*. 1994). It is rather perceived as an eco-centric value which is inherent to an ecosystem's self organizing capacity and hence determining ecosystem resilience. It is independent of human preferences, and irrespective of human desires or will.

Table 2 Categories and descriptions of ecosystem services (adapted from Defra, 2007)

Category	Services provided
Provisioning services (P) i.e. products obtained from ecosystems	• Food e.g. crops, fruit, fish • Fibre and fuel e.g. timber, wool • Biochemicals, natural medicines and pharmaceuticals • Genetic resources: genes and genetic information used for animal/plant breeding and biotechnology • Ornamental resources e.g. shells, flowers
Regulating services (R) i.e. benefits obtained from the regulation of ecosystem processes	• Air-quality maintenance: ecosystems contribute chemicals to and extract chemicals from the atmosphere • Climate regulation e.g. land cover can affect local temperature and precipitation; globally ecosystems affect greenhouse gas sequestration and emissions • Water regulation e.g. the timing and magnitude of runoff, flooding etc. • Erosion control: vegetative cover plays an important role in soil retention/prevention of land/asset erosion • Water purification/detoxification: ecosystems can be a source of water impurities but can also help to filter out/decompose organic waste • Natural hazard protection e.g. storms, floods, landslides • Bioremediation of waste i.e. removal of pollutants through storage, dilution, transformation and burial
Cultural services (C) i.e. nonmaterial benefits that people obtain through spiritual enrichment, cognitive development, recreation etc	• Spiritual and religious value: many religions attach spiritual and religious values to ecosystems • Inspiration for art, folklore, architecture etc • Social relations: ecosystems affect the types of social relations that are established e.g. fishing societies • Aesthetic values: many people find beauty in various aspects of ecosystems • Cultural heritage values: many societies place high value on the maintenance of important landscapes or species • Recreation and ecotourism
Supporting services (S) i.e. services necessary for the production of all other ecosystem services	• Soil formation and retention • Nutrient cycling • Primary production • Water cycling • Production of atmospheric oxygen • Provision of habitat

Table 3 *Soil related ecosystem services*

Key ecosystem services related to soil	**Abbreviation used in report**	**Ecosystem service categories as defined in the MEA[1] (2005)**
Provision of clean water	W	R
Provision of food, fibre and raw material	P	P
Flood mitigation	F	R
Provision of clean air including GHG concentrations	A	R
Provision of cultural services (including landscape/recreation, cultural heritage and archaeology)	C	C
Provision of attenuation/buffering of pollutants	B	R
Provision of a foundation for human infrastructure	I	P/C
Contribution of soils to biodiversity and landscape	L	P/R/C/S

[1] See Table 2; provisioning services (P) – regulatory services (R) – cultural services (C) – supporting services (S)

3.6 Data needs for quantifying economic impacts of soil degradation

Economic quantification of impacts of soil degradation for Scotland requires knowledge on;

(i) the biophysical impacts of soil degradation (i.e. the dose-response relationships), possibly expressed as changes in suitable indicators;
(ii) the geographical extent and/or the size of the soils affected by the impacts;
(iii) the quantification of the contribution of soil degradation, as opposed to other factors, to the economic impacts for private land managers and society;
(iv) the monetary values assigned to a marginal change in the indicators reflecting soil degradation.

Scotland is relatively rich in soils information from national surveys (e.g. the National Soil Inventory for Scotland), regional assessments (e.g. TIPPS (Trends in Pollution of Scottish Soils)) and detailed experimental studies (e.g. NERC Soil Biodiversity Programme and SEERAD's MICRONET study). Along with on-going RERAD research (http://www.programme3.net/index.php), this information is being used to inform on the status and trends in soil properties and processes, and increasingly, the consequences for soil functions[8]. There has been considerable development towards reliable indicators of soil quality for future monitoring (Aalders *et al*, 2009; Black *et al*, 2009). These indicators are primarily targeted at assessing the biophysical condition of soils with on-going research to establish action points or intervention values beyond which the functions of soils are compromised. Although soil functions have many parallels to ecosystem services, they are not entirely compatible. As a consequence, it is becoming increasingly clear that soil quality indicators now need to be assessed for their relevance to the delivery of ecosystem services. This will require further development of mapping the direct and indirect contributions of soil properties and processes, through soil functions, to ecosystem services. The table in APPENDIX A illustrates how this approach may be developed. Table 4 below shows the widely used list of soil functions. In assessing the economic impact categories, we linked them, if possible, to the soil functions affected (Sections 4.2. to 4.7).

Table 4 *Soil Functions*

Soil functions, as defined in the Scottish Soil Framework	**Abbreviation used**
Controlling and regulating water flow and quality	W, F
Controlling and regulating other environmental interactions e.g. degradation and retention of pollutants	B
Preserving cultural and archaeological heritage	C
Providing the basis for food, forestry and other biomass production	P
Providing valued habitats & sustaining biodiversity	L
Storing carbon and maintaining the balance of gases in the air	A
Providing raw materials	R
Providing a platform for infrastructure development	I

[8] The basic premise that underpins the soil function concept is that soils can be defined by their inherent capacity to deliver a range of functions and that degradation of inherent soil properties and processes will compromise the delivery of these functions with the sustainable use of soils only possible by a temporal and/or spatial "harmonisation" in soil functions (Blum, 2005).

Table 5 *Interactions between soil pressures (adapted and developed from Görlach et al., 2004)*

PRESSURE	Examples of interaction with other sources of degradation	Additional impacts (not necessarily related to other degradation types)
Soil erosion / landslides	Reduce the potential of soils to absorb rainfall may increase the severity of flooding events. Reduce the run-off potential of urban drainage systems and therefore contribute to pluvial flooding. Can lead to accelerated decline in soil organic matter. Increasing erosion negatively affects soil biodiversity (decreases activity and species diversity of soil biota and the amount of microbial biomass).	Reduces the capacity of soils to preserve archaeological remains. e.g. For peat bogs, degradation will directly impact on the function of soil as cultural heritage. On-site effects on agricultural production. Off-site impacts on water quality and ecology, sedimentation of water bodies and drainage systems, health (carrier of pathogens)
Compaction	May give rise to water and wind erosion. Reduces the potential of soils to absorb rainfall may therefore increase the severity of flooding events. May have significant impacts on below-ground biodiversity. Can reduce the capacity of soil to act as a buffer against pollutants. Can reduce nutrient availability, water availability and gas exchange in the soils so limiting plant growth	Severe compaction may reduce the capability of transferring land into a different use. May increase the amount of greenhouse gases (nitrous oxide) produced because of the poorer drainage. Nutrient deposition in floodplains can be a welcome aspect of agricultural production. Floods can contribute to soil contamination (by washing out pollutants and depositing them elsewhere).
Soil sealing	Increased sealing may increase and speed up run-off, contributing to flooding Increased sealing may increase soil contamination. (Runoff water from sealed housing and traffic areas is normally unfiltered and contaminated with chemicals). Can reduce the capacity of soil to act as a buffer against pollutants. Increased sealing may reduce soil biodiversity. (Soil sealing affects the fragmentation of habitats).	Soil sealing is often associated with a severe loss of many essential soil functions, e.g. regarding agricultural productivity
Contamination	Stress factors such as soil contamination and acidification have negative effects on soil biodiversity. Contamination can lead to water quality issues	Contamination can reduce plant productivity and quality
Decline in soil organic matter (OM)	Soil biodiversity is closely related to soil OM, because soils with an adequate amount of organic C have a good structure, allowing water and air infiltration and help provide favourable biological habitats. Decline in OM intensifies soil erosion; on the other hand, adequate amount of organic C makes soil more resistant to erosion. Decline in OM can reduce the capacity of soil to act as a buffer against pollutants.	Decline in OM is associated with a loss of carbon. If the decline is linked to water erosion, the carbon can be locked for a long time in river beds and the seabed. If the carbon is lost via oxidation due to disturbance, it will contribute to increased CO2 concentrations in the atmosphere
Loss of biodiversity	When biological activity of soil is reduced, the soil is less stable and more prone to erosion, as well as leaching and runoff causing water contamination.	Soil biodiversity loss can result in loss of aboveground biodiversity due to a reliance on unique symbioses

Quantification of the contribution of soil degradation as opposed to other factors generating impacts requires in depth knowledge of highly complex systems. These systems, in turn, are not isolated but interact with other systems. As value to humans usually arises from the use, consumption or enjoyment of end-products rather than the intermediate products or factors that together generate an end-product, teasing out soils' contribution to the value is difficult and in many cases impossible (see above section 3.5 Ecosystem services).

Due to interactions within and between the affected ecosystems, there are overlaps between the soil degradation types and soil pressures described below. Because of the multitude of functions that soil performs, soil degradation is an equally complex process. While specific patterns of soil degradation can be identified, it is not always possible to identify a particular threat to soil. Consequently, different types of soil degradation will often occur in conjunction, or will mutually reinforce each other (e.g. compaction may cause biological degradation; prevention measures against erosion also reduce risk of flooding; loss of soil organic matter: can impact on production value, etc.). **Hence, summing up the total cost estimates of all soil threats would result in an overestimate of the total cost of soil degradation for Scotland due to double counting**. Several interactions between soil pressures are listed in Table 5.

It is beyond the scope of this report to quantify the identified impacts for the soil pressures. However, we illustrate deriving monetary estimates for several of the cost categories for the six soil pressures in Appendix B.

3.7 A qualitative assessment of economic impacts for Scotland

We provide a simple assessment of the expected magnitude of impacts that reflects more of an ordering of impacts relative to each other in terms of relevance than an indication of the magnitude of costs/benefits. Also, temporal aspects of soil degradation are not considered specifically. In particular, this concerns long-term impacts (reversibility of soil degradation) and issues of time preferences and intergenerational justice.

Whether soil degradation is reversible is site-specific, as the reversibility depends on soil properties, the type and severity of degradation, as well as the tendency of the degradation to increase or decrease (van Lynden, 1995). In the assessment of the causes and drivers of soil degradation, this has to be taken into account: the same type of land use that is sustainable on one area of soil may be highly damaging on another area that has already been degraded. The impact that human activity will have on soil also depends on the "degradation history" of a site; furthermore, activities leading to immediate degradation of one type may indirectly contribute to other forms of soil degradation.

The second issue relates to time preferences. Standard economic theory assumes that the benefits derived from goods or services, e.g. the consumption of ecosystem services, are preferred sooner rather than later. This positive rate of time preference reflects the risks and uncertainties associated with deferred consumption. Consequently the nominal value of future benefits (and costs) should be discounted using an appropriate discount rate to estimate their present value. However, the use of discounting has important consequences for sustainability and intergenerational equity and justice as it effectively reduces the value of future benefits or costs, i.e. the future is valued less than the present and the interests of future generations are given lower weight than those of the current generation. Despite these concerns over the use of discounting, it is an important tool when comparing impacts that occur over different time frames. A more detailed assessment of the consequences of choosing time frame and discount rates was beyond the scope of this report. For time frames of projects up to 30 years, the UK Treasury (HM Treasury, 2003) recommends a discount rate of 3.5%.

To be able to provide some coherent overall picture, however, we based our assessment on a time scale of 20-25 years that links the assessment to data available from monitoring.

Our assessment was based on the following questions:

- How severe are biophysical changes resulting from soil pressure? This will be assessed by investigating impacts of pressures on soil functions (Table 4)
- What is the geographical extent of these changes in Scotland and who will be affected?
- What is the contribution of single economic impacts to the total costs related to any soil pressure?

With answers to these questions, we assigned an impact to one of three categories: low impact, medium impact or high impact. Where available, we used information on economic impacts from Görlach *et al*. (2004), ADAS (2006) and Defra (2009) to identify the magnitudes of impacts without adjustment for the Scottish situation**.** Based on expert judgment, we assessed how the relative magnitudes of impacts may differ for Scotland. This provided an anchor for assessing the relative expected magnitude of those impacts where no economic data was available. As mentioned above, the procedure resulted in a relative ordering of expected magnitudes of impacts and does not allow for quantifying the differences between the categories, e.g. between medium and high. If we were uncertain about the range of expected economic costs/benefits or the extent of biophysical change, we reflected this in our assessment by reporting a range, e.g. medium to high impact.

We also highlight whether economic estimates that are related to the impact categories are available in Görlach *et al*. (2004), ADAS (2006) and Defra (2009). It should be noted, however, that we do not explicitly assess the amount, quality or reliability of the data on which these estimates rest, the transferability of the values from different geographical regions to Scotland, and uncertainty or margin of error associated with the estimates.

4. OVERVIEW OF ECONOMIC IMPACTS OF SOIL PRESSURES

4.1 Approach

For each pressure we carried out the following tasks:

a. Described the state, drivers and trends from a biophysical perspective. Where data allowed, these quantified impacts were apportioned across the land uses that have a significant influence on each pressure. Where possible an assessment was made of change over time.
b. For each pressure, impacts that have an economic dimension were identified along with cost categories for each pressure, using the following:

- The on-site (private) costs associated with a loss or decline of soil's capacity to provide ecosystem services.
- The on-site (private) costs of mitigation arising from efforts to (partially) restore the capacity of soil to provide ecosystem services.
- Costs of defensive measures to prevent and reduce negative off-site effects.
- The off-site (social) costs of soil degradation arising from negative externalities.
- Under non-use costs we summarise all other costs that are not related to direct or indirect use of soil.

- For each cost category, we will assess the corresponding soil functions and ecosystem service categories (provisioning, regulating, cultural, supporting).
- Economic impacts will be assessed qualitatively as a group exercise using simple low, medium and high categories. Uncertainty can be expressed as a range. The group exercise effectively draws on the expertise of the interdisciplinary team.

As mentioned in section 3.7, it is important to note that we used expert judgment to assess how the relative magnitudes of socio-economic impacts may differ for Scotland in tables 6-11.

4.2 Decline in soil organic matter (OM)

a) Short description

Soil organic matter is a fundamental constituent of all soils. It is formed by the breakdown and incorporation of plant materials into the soil where it has a vital and varied role in maintaining a range of soil functions. The quality and quantity of soil organic matter within Scotland's soils varies as a reflection of environmental and human factors including land use, management, climate and topography and, in some cases, historical bioclimatic conditions. Peat soils hold the largest stores of soil organic matter in Scotland, with formation taking place over 1000's of year in a cool, wet climate e.g. 30 cm of peat can take >1,000 years to accumulate. Future climate change will be crucial in dictating further soil organic matter accumulation.

b) Biophysical description – impact of threat on status of soils and their functions

Biomass, food and fibre production. The cross-compliance framework on good agricultural and environmental condition (GAEC) indicates that land managers should maintain soil organic matter levels through appropriate practices, although there are currently no strict guidelines or thresholds for Scottish agricultural or forestry soils. In terms of biomass production, soil organic matter influences soil fertility, soil structure, workability and water holding capacity. Reductions in nutrient supply from soil organic matter loss can be replaced, in the main, by the use of fertilisers, except in organic farming systems where soil organic matter is a key macro- and micro-nutrient resource. Biomass production can be limited by degradation of soil physical structure, through a loss in soil organic matter, since soil organic matter helps to provide an amenable physical environment for effective crop root growth and water uptake.

Regulating water flow and quality. Soil organic matter has a fundamental role in the filtering, buffering and purification of water. The capacity for soil to accept retain and transfer water will be diminished with significant losses in soil organic matter, although "significant" levels remain as yet uncharacterised for individual Scottish soil types or vulnerable locations. Organic soils (e.g. peats) have a key role in mitigating flooding and in this instance with the spatial extent of soil organic matter loss as important as the total C loss. The transfer of pollutants from soil to water bodies also increases as soil organic matter is degraded. For example, in catchments dominated by organic soils, increasing concentrations of dissolved organic carbon (DOC) are a reflection of changes to soil organic matter quantity and/ or quality.

Storing carbon and maintaining the balance of gases in the air. Since carbon is a major component of soil organic matter (ca. 50%), it is obvious that any loss in soil organic matter will result in a reduction in the Scottish soil carbon store; Scotland's organic soils alone contain 2735 Mt of carbon. Recent national-scale surveys indicate that topsoil carbon has not been significantly reduced in the last 30 years, although there have been reductions in arable soils. Recent estimates suggest that within the UK, the pool of soil C is slowly accumulating C at a rate of 0.22 Mt/y in 2000 (as reported to UNFCCC). Loss in soil organic matter can also translate into increased emissions of greenhouse gases from soils (CO_2, CH_4 and N_2O). For example, the majority of N_2O emissions from Scottish agriculture are attributable to the management and use of soils and increased turnover of soil organic matter can result in increased N_2O emissions. Highly organic soils also release CH_4, although this is < 10% of national GHG emissions. Peatland restoration is seen as a major potential to achieve carbon gains, along with habitat and biodiversity improvements.

Support of ecosystems, habitats and biodiversity. Losses in soil organic matter reduce the primary energy source for soil organisms and degrade a (soil) physico-chemical environment conducive for healthy growth and reproduction. Many soil organisms of a recognised conservation status are associated with native and semi-natural habitats, where both the quality and quantity of soil organic matter are important determinants of occurrence. In turn, losses in soil organic matter, whether through erosion, increased GHG releases or DOC losses, are an indication that the function of ecosystems / habitats has been degraded.

Provision of raw materials. In Scotland, peat reserves have been exploited for many centuries as a domestic fuel source and, more recently, for horticultural purposes. Peat is also used to dry malted barley in whisky production. In recent decades there has been a rapid decline in the use of peat resources with alternatives being promoted for growing medium, and with changes to domestic practices. The remaining reserves of Scottish peat therefore retain the capacity to provide raw materials but this reserve is increasingly being conserved and protected for other functions.

Protection of cultural heritage. Many of Scotland's soil archaeological remains are preserved within organic soils and therefore, degradation of this resource can have significant implications for the protection of this heritage. For example, degradation of remains is threatened by degradation in the quality of soil organic matter as a consequence of increases in nitrogen content from atmospheric inputs or in the dehydration of soil organic matter. With respect to impact category 1.7, it is worth noting that small-scale removal of peat can have cultural significance, e.g. by maintaining archaeological heritage.

c) Costs

Table 6 *Overview of economic impact categories for Scotland associated with decline in soil organic matter (OM)*

No	Imp. cat.[5]		ES[1]	SF[2]	Impact[3]	Data Status[4]
		On-site costs				
1.1	PC	OM is a key factor for soil fertility; beyond a certain threshold, OM decline results in losses of *agricultural productivity* (i.e. yield losses)	P	P	**	Y
1.2	MC	Restoration of higher OM levels or costs associated with *higher input requirements*	P	P	**	Y
		Off-site costs				
1.3	SC	*Reduced capacity for pollution retention* from OM decline can directly affect ground and surface water quality and availability.	W	W	* - ***	N
1.4	SC	OM loss equals a loss in carbon; microbial decomposition can turn organic carbon into GHGs with *impacts on atmospheric concentrations of GHGs*.	A	A	***	Y
1.5	DC	Costs of defensive measures against *climate change impacts* (resulting from OM-related increases in GHGs)	-	A	* - ***	N
1.6	NC/ PC/ SC	OM decline can be associated with losses in soil biodiversity (NC) and hence a deprivation of the genetic resource limiting its potential for future commercial/societal use (PC/SC)	C, L	L	* - ***	N
1.7	NC	If OM levels drop beyond thresholds a shift in land cover can impact on *landscape/amenity values* (e.g., peat extraction/erosion)	L, C	L, C	* - **	N

[1] Ecosystem services related to economic impact category (Section 3.5); [2] Soil functions affected (Section 3.6); [3] Impact assessment for Scotland (see Section 3.7) * low, ** medium, *** high; [4] Economic estimates related to the impact categories (Y Yes; N No) are available in Görlach et al. (2004), ADAS (2006) and Defra (2009); [5] Economic impact categories as defined in Section 3.4.

d) Examples that could be applicable to Scotland:

Impact No	Examples
1.4, 1.3	Prevent further degradation of peatland (e.g. in Flow Country)
1.4, 1.3	Construction of windfarms on organic soils – reduced water holding capacity and release of GHGs
1.3	Extra soil input costs of continuous cropping on sandy soils (Morayshire)

4.3 Soil sealing

a) Short description

Soil sealing refers to the permanent covering of the soil surface with an impermeable material. In most circumstances, this includes new residential, retail or industrial developments but new transport links are also included. Renewable energy developments are also included, notably wind farms, and although only a small part of these sites are permanently sealed, their impact can extend beyond the land occupied by the turbines.

b) Biophysical description – impact of threat on status of soils and their functions

Biomass, food and fibre production. Loss to development prevents soil performing this function to any great extent. Although some land will be retained for gardens and allotments, the rural attributes and food production capacity of the land has been irreversibly changed. Nevertheless, soils within urban areas are being increasingly recognised for their contribution to social cohesion and recreation in addition to local food production.

Regulating water flow and quality. This function will be seriously diminished, but is retained to some small degree in gardens, amenity areas, roadside verges etc. However the major impact on soil function is the reduction in infiltration of water which leads to change in hydrological regimes in rivers, specifically greater runoff and peak flows. There is also concern that construction associated with windfarms on vulnerable soils may lead to increased sediment transport to water courses.

Storing carbon and maintaining the balance of gases in the air. Soil contains large amounts of carbon and even if the soil is re-used after stripping, the disturbance involved in engineering works means that some of this will be lost. Soil sealing and activities subsequently associated with developed land result in deterioration of both the soil's ability to store carbon and regulate GHG exchanges and in air quality in a more general sense.

Support of ecosystems, habitats and biodiversity. Overall, soil sealing has a highly negative impact on soil biodiversity although the current planning system and designation of sites of high conservation interest should prevent development on land with valuable and/or rare habitats and sites of high biodiversity. It is also worth pointing out that most of the extensive areas of valued and/or rare habitats in Scotland are not found adjacent to potential development sites. However, there will be specific areas where conflicts may arise, notably on the location of wind farms and where conservation and development objectives may clash, for example within National Parks. Restoration of brownfield sites within urban areas could represent a biodiversity gain but care is required on the use of species; many non-native species are introduced into urban areas.

Provision of raw materials. Depending on the site, resources such as sand, gravel and clay can be exploited during the initial development phase; indeed this might be viewed as maximising the use of the resource. In addition, soil stripping is part of the development process. Ideally the soil removed should be re-used on site for landscaping and amenity areas. As a substantial proportion of the site is likely to be covered by buildings, roads etc, surpluses can occur. These can be used in areas, particularly of redevelopment, where topsoil is in short supply but clearly this requires a high degree of co-ordination. It must also be recognised that there are environmental and economic costs associated with the transport of soil as well as the social costs of dust and noise nuisance.

Protection of cultural heritage. Soil protects archaeological remains but also provides a record within it of previous cultivation and improvement and therefore of the development of landscapes and societies. It might be argued that urbanisation is another step within the process of change, but the disturbance and redistribution of soil associated with that does destroy any historical record of change captured within the soil.

Providing a platform for buildings and roads. Essentially this function of soil is being exploited in the sealing process.

c) Costs

Table 7 *Overview of economic impact categories for Scotland associated with soil sealing*

No	Imp. cat.[5]		ES[1]	SF[2]	Impact[3]	Data Status[4]
		On-site costs				
2.1	PC	Opportunity costs of *alternative land use activities*, potentially including a reduction of a country's capability to produce food (perceived food security) (SC)	I, P	I, P	*-***	N
2,2	MC	Cost of *de-sealing* and restoration	I	I	*-**	N
		Off-site costs				
2.3	SC	Impacts on *water quality* due to unfiltered run-off and exposure to contaminants (housing, industry, traffic)	W	W	**	N
2.4	SC	Compromises *nature conservation*; habitat fragmentation and interruption of migration corridors	L	L	*	N
2.5	SC	Impacts on *climate change* related damage due to removal of topsoils and subsequent release of GHGs	A	A	**	Y
2.6	DC	Indirect costs of *retaining and channelling water* from sealed surfaces and cleaning/filtering it	W	W, F	*	N
2.7	NC	*Landscape/amenity values* can be compromised	L	C	**	N

[1] Ecosystem services related to economic impact category (Section 3.5); [2] Soil functions affected (Section 3.6); [3] Impact assessment for Scotland (see Section 3.7) * low, ** medium, *** high; [4] Economic estimates related to the impact categories (Y Yes; N No) available in Görlach *et al*. (2004), ADAS (2006) and Defra (2009); [5] Economic impact categories as defined in Section 3.4.

d) Examples that could be applicable to Scotland:

Impact No	Examples
2.1	Annual extent of new developments on prime agricultural land
2.6	Costs of instating artificial sustainable urban drainage systems ("SUDS")
2.3	Developments on areas of conservation status

Regarding 2.5: ADAS (2006) report that urbanisation would result in annual loss over 5 years time horizon of £210 per ha per year for carbon which is priced at £70/t C (Clarkson and Deyes, 2002)[9]. Because little is known about end-use of the removed topsoil, it is unclear how much of it will end up as CO_2 in the atmosphere. However, this figure can be put

[9] The UK Government has published a number of reports on the cost of carbon (or CO_2e) based on this initial study (e.g. Price *et al*., 2007). Common to each is that the cost per tonne emitted increases over time (e.g. an additional £1 per tonne CO_2e per annum) to reflect the increasing marginal damage caused by cumulative emissions. It is therefore necessary to apply the correct year's value to any emissions or abatement.

into perspective with the annually sealed or developed area in Scotland (~1,200 ha) to derive at a rough estimate of costs associated.

It should be noted that the impact categories above can have a direct beneficial counterpart. For example, landscape values may be compromised but roads open up access for a larger amount of people to enjoy these landscapes in the first place. These examples demonstrate that soil management strategies should, from an economic point of view, not always aim at fully extinguishing threats to soil, but rather aim at finding a social optimum of soil degradation (Kuhlmann *et al*., 2008). Moreover, the costs of soil sealing are highly depended on the spatial context (the initial extent of sealed soil; in urban areas, drainage capacities; rainfall patterns; the organic matter content of soil on which a project is planned) and the layout of a development project (e.g., how water flows are planned etc). Hence, the costs of soil sealing are best assessed as part of the planning process in economic impact assessments (cost-benefit analyses) of individual projects where costs of soil sealing are part of environmental impacts and are weighted against the benefits expected from the development. Costs can be significant and impacts of soil sealing should – due to the irreversible damage to the soil resource – find greater appreciation in planning procedures.

4.4 Pollution

a) Short description

Towers et al. (2006) identified three main pollution[10] threats to Scottish soils: atmospheric deposition, persistent organic pollutants and heavy metals. Pollution is a consequence of human activities at local to international scales e.g. industrial activities, traffic pollution, emissions from agriculture or waste disposal. In several locations, these are the historical consequences of 19th and 20th Century industrial and mining activities. The most widespread contamination of Scottish soils has been from acid rain and, to a lesser but increasing extent, nitrogen deposition. Scottish soils are now recovering from acid rain but nitrogen (N) deposition continues to be an issue. Pollution can impact on soils in many different ways which depends partly on the concentrations of the contaminant but also on the capacity of the soil type to buffer, retain or degrade the contaminant. For example, many organic pollutants can be broken down into less harmful compounds over time while the threats from metal contaminants is bounded by soil pH, soil organic matter content and soil texture.

b) Biophysical description – impact of threat on status of soils and their functions

Biomass, food and fibre production. Existing statutory thresholds for the concentrations of heavy metals in grains (e.g. Cadmium) reflect the significance of metal contamination of soils to food production since many plants will accumulate metals from soils while excessive metal levels can limit plant growth and yields. In contrast, nitrogen deposition stimulates plant growth and biomass production although excessive N deposition can lead to acidification of soils, paralleling past acid rain impacts. As a consequence, lowering soil pH may require remedial action to maintain biomass production.

Regulating water flow and quality. Soil contamination can become a major pollution issue for water quality as the natural capacity of different soils to buffer, attenuate and degrade pollutants is exceeded. This results in the release of contaminants to waters through leaching or sediment erosion. It can be difficult to restore this capacity without significant management interventions which may take decades to be effective. Within agricultural systems, nitrate and phosphorus leaching, and pathogen transfers, can be of concern while

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[10] Pollution is the introduction of contaminants into an environment that causes instability, disorder or harm to ecosystems.

increases to DOC concentrations may reflect pollution impacts (e.g. N and/or S deposition) in semi-natural systems dominated by organic soils.

Storing carbon and maintaining the balance of gases in the air. Both atmospheric deposition of nitrogen and sulphur influence the dynamics of soil nutrient and carbon cycling and, as a consequence, alter the mechanisms of soil carbon storage and release of GHGs from soils. There is, however, considerable debate regarding the long-term consequences of continued nitrogen deposition on soil carbon stores. High levels of heavy metals have been shown to inhibit soil organic matter decomposition with resultant increases in soil carbon stores.

Support of ecosystems, habitats and biodiversity. Pollution from all sources can result in the impairment of soil, and wider ecosystem, function. These can be direct losses on biodiversity or its "quality", for example many fungi are sensitive to nitrogen which alters species occurrence and community structure while some fungal species have been shown to hyper-accumulate radionuclides from nuclear incidents (e.g. Chernobyl). Habitats reliant upon nutrient-poor soils can be compromised by increases in soil nitrogen or other nutrient levels.

c) Costs

We distinguish contamination activities that can result in pollution of the soil resources by source:

Point source:

- municipal and industrial waste disposal sites
- industrial and commercial sites
- mining sites
- former military sites
- oil extraction
- other soil contamination sites (e.g. shooting ranges)

Diffuse sources:

- Waste disposal or use of chemicals in the landscape
- Contaminants with origin from atmospheric deposition

Table 8a gives an overview of impact categories that are mainly, but not exclusively, associated with point sources e.g. from industrial sites while Table 8b summarises impact categories associated with atmospheric deposition specifically since this is a significant source for Scotland. Issues associated with endocrine disrupting compounds and pathogens are discussed separately and illustrate the uncertainty associated with soil-related pathways and impacts.

Atmospheric deposition can contribute to eutrophication and acidification and so there is a high risk of double counting if the issues are assessed separately with the values added. Costs can be high as indicated by WTP for WFD improvements (Lago and Glenk, 2009) and reported by ADAS (2006). It is difficult however to apportion sources e.g. P pollution of waters that is related to soil may vary between 25% and 50% or more. Nitrate removal by water companies is 80% attributable to agriculture (ADAS, 2006; Pretty *et al*., 2000) and zoonoses removal to 90%. Mitigation costs in agriculture vary greatly depending on measure, targeted pollution reduction (marginal costs) and land use. Atmospheric deposition can also be beneficial in certain cases, for example by reducing input costs (fertiliser, lime) while it is important to consider the environmental interactions between atmospheric deposition and impacts on water (e.g. acidification potentially increasing nitrate leaching).

Table 8a *Overview of economic impact categories for Scotland associated with contamination*

No	Imp. cat.[5]		ES[1]	SF[2]	Impact[3]	Data Status[4]
		On-site costs				
3.1	PC/ SC	Costs of *monitoring and risk/impact assessments*	-	B	*	Y
3.2	PC/ SC	Costs of *protection* of workers and/or the public from exposure to harmful substances	-	B	*	N
3.3	PC	Costs of *land/property depreciation* (estimated with damage function)	-	B, I	*	N
3.4	MC	Costs of *decontamination* or site clean-up after use	-	B, I	***	Y
		Off-site costs				
3.5	SC	*Health impacts* of contacts with pollutants/contaminants (e.g., radioactive nuclides, heavy metals, microbes) and of consumption of contaminated products (e.g. mushrooms) with associated costs of treatment and wage loss	-	B	***	Y
3.6	SC	*Contamination of agricultural land* constraints usage (e.g. from farming to forestry); results in loss of farm income and property value of land	P	P, B	*	N
3.7	PC/SC	*Legal restrictions to using land* for certain purposes can have negative impact on land/property value	-	B, I	*	N
3.8	SC	*Real estate* within or close to contaminated sites can decline in value due to perceived threats to health	-	B	*-**	N
3.9	SC/ NC	Pollutants/contaminants in soils can be washed out into surface water bodies or use soil particles as vehicles to be transported to water bodies. *Impacts on surface water quality and ecology* (e.g. fish stocks), with costs emerging from constrained usage of water bodies and consumption of products from these.	W, L	W, B, L	**-***	Y
3.10	SC	Costs associated with *groundwater contamination* (e.g. additional treatment necessary)	W	W, B	**	Y
3.11	DC	Defensive costs related to the *prevention of contaminants to spread* (via soil, air, water; e.g. covering contaminated soils to prevent leaching or transport to surface water bodies)	B, A, W	B, W, A	*-**	N

[1] Ecosystem services related to economic impact category (Section 3.5); [2] Soil functions affected (Section 3.6); [3] Impact assessment for Scotland (see Section 3.7) * low, ** medium, *** high; [4] Economic estimates related to the impact categories (Y Yes; N No) are available in Görlach et al. (2004), ADAS (2006) and Defra (2009); [5] Economic impact categories as defined in Section 3.4.

Table 8b *Overview of economic impact categories for Scotland associated with atmospheric deposition*

No	Imp. cat.[5]		ES[1]	SF[2]	Impact[3]	Data Status[4]
		On-site costs				
3.12	PC	Costs of *monitoring and risk/impact assessments* (site specific)	P[6]	B	*	N
3.13	PC	Costs associated with *loss in productivity* resulting from change in soil biodiversity	P	P, B	*-**	N
3.14	MC	Costs of *restoration practices* to reduce nutrient levels in soils	P	P, B	*-**	N
3.15	MC	Costs associated with mitigating the transport of pollutants to soils (e.g. tree buffer zones for chicken farms)	P	P, B	*	N
3.16	MC	Costs associated with *remediating against reduced soil pH* as a consequence of acid rain (e.g. additional liming)	P	P, B	*	N
		Off-site costs				
3.17	SC	Costs of *monitoring and risk/impact assessments* (national to international)	B[6]	B	*	N
3.18	SC	*Costs associated with surface and groundwater contamination* (e.g. removal of nitrates from drinking water).	W	W, B	*-**	N
3.19	SC	Increased *emissions of GHGs* from soil nutrient enrichment (in particular N_2O)	A	A	*-**	N
3.20	SC/NC	Costs associated with reduced *habitat quality* through feedbacks from soils to above-ground plants (acidification and eutrophication)	L, C	L, B	*-**	N
3.21	SC	*Impacts on freshwater ecology* (e.g. eutrophication) with costs emerging from constrained usage of water bodies and consumption of products from these	L, C, W	W, B	*-**	N
3.22	DC	Costs of defensive measures to *prevent deposition* induced erosion and degradation and erosion of organic soils	L, A	L, A	*	N

[1] Ecosystem services related to economic impact category (Section 3.5); [2] Soil functions affected (Section 3.6); [3] Impact assessment for Scotland (see Section 3.7) * low, ** medium, *** high; [4] Economic estimates related to the impact categories (Y Yes; N No) are available in Görlach et al. (2004), ADAS (2006) and Defra (2009); [5] Economic impact categories as defined in Section 3.4. [6] Monitoring and impact assessment may be related to many ecosystem service categories depending on the contaminant, i.e. the reason why it needs to be monitored.

Endocrine disrupting compounds are anthropogenic organic pollutants which are derived from industrial and domestic sources and include compounds such as phthalates, polycyclic aromatic hydrocarbons (PAH), polybrominanted diphenyl ethers (PBDE) and polychlorinated biphenyls (PCB). These compounds are generally slow to degrade, ubiquitous and can act additively (with other organic pollutants and with heavy metals) to exert biological effects on species as diverse as bacteria and humans. For example, it has been shown that the reproductive systems of ruminants grazing pastures fertilised with sewage sludge can be disrupted[11]. However the economic impact of endocrine disrupting compounds in soils is currently difficult to quantify.

Pathogens reach the soil from various sources including sewage sludge, septic tank outlets, municipal compost and other wastes derived from industrial utilisation of agricultural products, such as abattoir wastes and pose potential risk to receptors such as humans, crops and grazing animals. The pathogens of concern include bacteria, viruses and protozoa e.g. *Escherischia coli* O157, *Salmonella* spp., *Cryptosporidium, Campylobacter* and *Giardia*. According to ADAS (2006, 63), at the moment it is impossible to estimate the marginal valuation of changes in a soil's ability to attenuate pathogens. The economic impact to be quantified would be both the costs associated with health risks borne from pathogen infections and the role soils or soil management would play in contributing to changes in risk. The pathways from the source (e.g. animals in case of *E. coli*) to exposure and actual infection are complex (see Figure 2). Soil can play a role in here (Habteselassie *et al*., 2008) but it is difficult to quantify this role in economic terms at present.

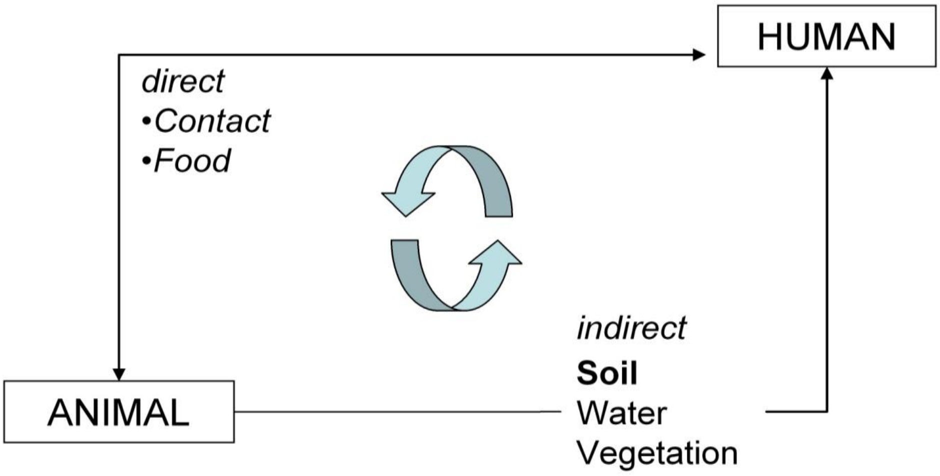

Fig. 2 *A simple representation of possible transfer routes of pathogens to humans*

d) Examples that could be applicable to Scotland:

Impact No	Examples
3.1, 3.2, 3.4	Remediation of contaminated soils prior to development
3.5, 3.9, 3.10, 3.11	Water purification costs (e.g. removal of heavy metals in the Central belt)
3.18	Reduced water quality e.g. acid waters and nutrient enrichment of waters
3.20	Loss in fungi of conservation status (e.g. tooth fungi) – see also Section 4.5
3.14, 3.20	Restoration costs to reduce nutrient enrichment, e.g. in sensitive habitats (for example matting, liming, removal of topsoil)

[11] Thanks to S. Rhind (Macaulay Land Use Research Institute) for providing information on this paragraph.

4.5 Soil biodiversity

a) Short description
Most of the biodiversity in Scottish soils is invisible to the eye but nevertheless vital to our environment and human welfare. Soil biodiversity refers to all organisms which spend part or all of their life cycle in the soil for feeding, nesting, hibernating or foraging such as;

- microbial organisms e.g. bacteria, fungi,
- invertebrates e.g. nematodes, and earthworms.
- vertebrates e.g. badgers and moles.

Soil biodiversity can be expressed by the genetic characteristics of individual organisms, different species and communities or what individuals, species and communities do (function). Functional diversity drives the biological processes which breakdown soil organic matter, produce greenhouse gases, and turn over soil so acting as nature's plough. It is also responsible for many antibiotics, such as penicillin.

A number of pressures on soil biodiversity have been identified including climate change, land use change, land management practices, loss and damage of habitats, invasive species and contamination. The responsiveness of soil biodiversity to the various pressures upon it will not only be determined by the characteristics of the intrinsic soil biodiversity but also by several factors, including land use and management histories and pre-existing stresses.

b) Biophysical description – impact of threat on status of soils and their functions

Ecosystem support: Soils themselves provide a habitat for soil organisms which can have both positive e.g. mycorrhizal fungi and detrimental effects on other forms of life e.g. disease causing organisms for livestock e.g. E. coli O157. There are plant/soil microbe symbioses which are fundamental to the survival of iconic species such as the Scottish bluebell. Many organisms are a food source for higher life forms such as birds, hedgehogs etc.

Environmental interactions: Biodiversity is fundamental in terms of environmental interactions. Low soil infiltration rates and water holding capacity can increase the risk of soil erosion and flooding. Both rely on a good soil structure and the relevance of soil organisms is noted above. Water lost from soils either from surface run-off or drainage can carry pollutants such as nutrients and pathogens. The build up of soil carbon and production of greenhouse gases from soils reflect the activities of soil biodiversity, in particular soil microorganisms, under certain soil physical and chemical conditions. Pressures which alter the biological cycling of carbon and nitrogen can therefore affect the net balance of soil carbon and GHG emissions.

Biomass support: Soil biodiversity is fundamental to the maintenance of biomass production by regulating nutrient supply to plants, helping to maintain a good soil structure, acting as biocontrol agents and contributing to plant pollination. Conversely, soil organisms can also cause significant losses to crop productivity through pests and diseases. Soil microbes and invertebrates work together in the soil food web to breakdown and cycle soil organic matter which releases nutrients for plant growth. Soil organisms help to generate and maintain good soil structure by forming pores and aggregates; microbes excrete organic compounds that act like glue to hold soil particles together; fungal mycelia bind particles mechanically while worms act to mix and reorganize soil particles and support water movement by building channels through soil. Native pollinators, many of which nest in the soil, are important for fertilising crops and wild plants as well as in the production of key Scottish products like honey. Some soil organisms like Potato cyst nematode are major pests in agriculture but other organisms have an important biocontrol role. The need to manage biodiversity for crop health is likely to increase as climate change may bring in new pests at a time when regulation is removing use of many common pesticides.

Provision of raw materials: Cultured soil organisms have long been a highly productive source of pharmaceuticals, such as antibiotics or drugs for cancer. Since less than 1% of all soil microorganisms can be cultured using current techniques, there is the expectation that a huge potential remains undiscovered.

c) Costs

Note that OM and soil biodiversity are closely related. Hence, it is difficult to separate economic impacts of loss of soil biodiversity from OM decline, soil erosion, contamination and compaction. In ecosystem service terms, soil biodiversity has an essential role as a supporting service. In general, soil biodiversity contributes greatly to the resilience of ecosystems. However, it is difficult to value changes in soil biodiversity in economic terms, because the value of soil biodiversity is often incorporated in end-products provided by soil-related regulatory and production services.

The relationships between soil biodiversity and soil functions and their contribution to socio-economic impacts is still poorly quantified (an exception is the relationship between soil biodiversity and crop yield, and the role in nitrogen fixing which affects grassland production). Hence, we are unable to evaluate the relevance of different impact categories against each other. Soil biodiversity has great value as a supporting service, which is, however, difficult to quantify. As a first step, it would be useful to identify how marginal changes in soil biodiversity impact on the categories above. Threshold effects should be identified and, in the absence of reliable cost-benefit data, a precautionary approach for managing soil biodiversity should be preferred over cost-benefit approaches.

Table 9 *Overview of economic impact categories for Scotland associated with decline in soil biodiversity*

No	Imp. cat.[5]		ES[1]	SF[2]	Impact[3]	Data Status[4]
		On-site costs				
4.1	PC	Soil biodiversity underpins a number of important soil functions and thus is an important factor determining soil fertility with impacts on *agricultural productivity*	P	P	**-***	N
4.2	PC	Because of its central role for several soil functions, change in soil biodiversity can result in *loss of buffering and recovering functions*. Susceptibility to other (soil) threats increases, with	P	P, W, B	*-***	N

		consequences for private land owners				
4.3	MC	*Cost of increased inputs* to agricultural production (fertilisers, pesticides) and more capital or labour intensive management practices	P	P	**-***	N
		Off-site costs				
4.4	SC	Change in soil biodiversity can result in *loss of buffering and recovering functions and services*	B	B	*-***	N
4.5	SC	Change in soil biodiversity can result in *reduced potential of soils to sequester carbon* or affect release of GHGs (possibly also PC)	A	A	*-***	N
4.6	DC	Replacement costs for *lost buffering* (regulatory services) e.g., technical remediation instead of bioremediation	B	B	*-***	N
4.7	NC/ PC/ SC	Changes in genetic resources present in soil can limit the *gene pool* available for potential future use (PC/SC); soil biodiversity may be valued for non-use or bequest reasons (moral, ethical) (NC)	C, L	C, L	*-***	N
4.8	NC	In extreme cases, changes in soil biodiversity will result in different land use/vegetation patterns and hence impact on *landscape appearance*	L, C	L, C	*-***	N

[1] Ecosystem services related to economic impact category (Section 3.5); [2] Soil functions affected (Section 3.6); [3] Impact assessment for Scotland (see Section 3.7) * low, ** medium, *** high; [4] Economic estimates related to the impact categories (Y Yes; N No) are available in Görlach et al. (2004), ADAS (2006) and Defra (2009); [5] Economic impact categories as defined in Section 3.4.

d) Examples that could be applicable to Scotland:

Impact No	Examples
4.7	Costs associated conserving or reinstating species of conservation value (e.g. tooth fungi)
4.1, 4.2, 4.3	Costs of replacing the N-fixing function of rhizobium in agricultural soils contaminated with Zn
4.7	Potential of discovering new pharmaceutical products in soils
4.5	Use of nitrification inhibitors to regulate the function of soil microbes and reduce the release of N_2O (see Moran *et al.*, 2008)

4.6 Soil erosion

a) Short description

The major processes considered are water erosion, mass movements and wind erosion, although tillage displacement is increasingly recognised as a significant contributor to soil erosion rates. Soil erosion is a natural process which occurs in all soils to a greater or lesser extent. Soil erosion becomes of concern when the rate exceeds “natural” or “background” rates which can be considered as broadly equal to the rate of formation of new soil material by weathering processes. Based on estimates of soil renewal rates, Kirkby (1980) proposed a soil loss tolerance value of 0.1 mm per year for the UK.

b) Biophysical description – impact of threat on status of soils and their functions

Food and other biomass production. One major impact of soil erosion is that it generally involves loss of the productive and fertile topsoil leading to a potentially significant threat to the biomass production of the soil. At its most extreme “The dust bowl” in the United States during the 1930s represents an extreme manifestation of this pressure. In contrast, soil losses in Scotland tend to occur on a fairly localized scale and eroded soil is often trapped at field boundaries such as walls and hedges. In some instances farmers simply move eroded soil back upslope. Given the relatively low frequency of erosion events and the short transport distances of eroded soils any threat to the biomass production function by soil erosion in Scotland must be viewed as small.

Environmental Interactions. Soil erosion has significant off-site effects on surface waters through silting up and reduced capacity of water-supply reservoirs, loss of fish spawning areas through the deposition of fine sediment on river-bed gravels and contamination of river waters by nutrients (mainly phosphorus) or pesticides adsorbed on eroded sediment particles. These effects are now considered within river basin management under the European Water Framework Directive (WFD), and this has led to many policy initiatives which currently protect soils such as the Forests and Water Guidelines. This is a trend which is likely to continue in future as the implementation of the WFD continues.

Storing carbon and maintaining the balance of gases in the air. Soil erosion can reduce the carbon storage function of soils as soil losses generally come from the more organic topsoil layers. This is true for both mineral and more organic soils. In upland areas the incidence of erosion may contribute to the increases in fluxes of DOC from upland peaty catchments. Further research to quantify the links between soil erosion and the carbon storage function of soils will undoubtedly be needed.

Biodiversity: As with food and biomass production, loss of fertile topsoil through severe erosion can have a significant impact on soil biota and on ecosystem functioning.

Provision of a platform: Erosion can damage the built infrastructure by undermining foundations and depositing sediment. Landslides triggered by extreme rainfall during the summer of 2004 caused significant damage to parts of the trunk road network.

Provision of raw materials. Large scale erosion of peat represents the major threat to the soil’s function in providing raw materials. Notwithstanding the fact that large scale exploitation of peat as an organic amendment or fuel is in steep decline, nevertheless, erosion is a threat to that function of peat.

Protection of cultural heritage. Soil erosion poses a threat to archaeological features such as buried crop marks, as loss of topsoil will ultimately lead to plough damage to such features preserved in cultivated soils.

c) Costs

Table 10 *Overview of economic impact categories for Scotland associated with soil erosion*

No	Imp. cat.[5]		ES[1]	SF[2]	Impact[3]	Data Status[4]
		On-site costs				
5.1	PC	Loss of *agricultural productivity* (damage to crops; increased input requirements; loss of seed and plant material, fertiliser, pesticides)	P	P	*-**	Y
5.2	PC	Costs of *sediment removal* from ditches (e.g. for drainage)	P	P	**	Y
5.3	MC	Costs of *erosion prevention*, e.g. field	P	P	*	Y

		buffers				
		Off-site costs				
5.4	SC	Costs of *sediment removal* (from roadside ditches; reservoirs; navigable waterbodies); in case of wind erosion costs of removal/clean-up costs of roads and buildings and costs of damage to technical equipment	-	-	**-***	Y
5.5	SC	*Damage to infrastructure* (roads, water supply systems)	-	-	*	Y
5.6	SC	*Impacts on health*; Wind erosion: respiratory illnesses; water erosion: soil particles as carriers of pathogens (see also Section 4.4 Contamination)	A, B	B	*	N
5.7	PC/ SC	Damage from *floods and land- or mudslides*	F, B	W, B, F	**	Y
5.8	SC	Cost associated with erosion-related *water treatment*	W	W	**	Y
5.9	SC	Impact on *recreational activities* (indirect effects due to adverse impacts of erosion on waterbodies or landscape amenity values)	C, L	-	*-***	N
5.10	SC	*Climate change impacts* of soil OM being released as CO_2 as a consequence of decreased stability of OM compounds in soil (see 4.2 OM loss) (Some organic carbon from OM loss is deposited in sediments where it does not contribute to climate change)	A	A	***	Y
5.11	DC	*Defensive expenditure to reduce off-site impacts* of erosion (e.g., shelterbelts against wind erosion along roads; sediment traps in ditches and streams)	?	W, F	*	N
5.12	NC	Reduced non-use values due to *adverse impacts on natural ecosystems* (e.g. eutrophication of waterbodies)	L, C	L, C	*-***	Y

[1] Ecosystem services related to economic impact category (Section 3.5); [2] Soil functions affected (Section 3.6); [3] Impact assessment for Scotland (see Section 3.7) * low, ** medium, *** high; [4] Economic estimates related to the impact categories (Y Yes; N No) are available in Görlach et al. (2004), ADAS (2006) and Defra (2009); [5] Economic impact categories as defined in Section 3.4.

d) Examples that could be applicable to Scotland:

Impact No	Examples
5.5	Reinstating infrastructure (e.g. roads) after landslides
5.5	Losses to local businesses if transport network is disrupted (e.g. Loch Fyne and the Rest and be Thankful diversion)
5.4, 5.8	Removal of sediment from water (dredging, water treatment for drinking water)
5.1	Loss of carrot seeds (Morayshire)

4.7 Compaction

a) Short description

Soil compaction generally refers to the loss of porosity through mechanical damage to soil and it can affect both topsoil and subsoil. Soil compaction resulting not only from agriculture but also from forest harvesting, industrial activities such as mining, pipeline installation, wildlife trampling and amenity land use is a long-term issue (Batey 2009). Compaction occurs when an external mechanical stress exceeds the mechanical stability of soil. The main causes are tillage machinery, wheels and livestock.

The susceptibility of a given soil to damage will depend on a number of properties including previous history, soil organic matter content, texture and structure. Soil water content is the greatest temporal variable influencing soil compaction so changes in precipitation associated with climate change could have a major influence on the extent of soil compaction in the future. Soils wetter than field capacity are at greatest risk and thus there is an interaction with soil type and presence or absence of field drainage. This has particular implications in agriculture when some operations e.g. harvesting of root crops are almost always carried out when soil is at or beyond field capacity.

b) Biophysical description – impact of threat on status of soils and their functions

Compaction affects a wide range of soil physical, chemical and biological properties and thus functions. By impacting soil structure, compaction influences water and air movement thus affecting nutrient cycling processes, habitats for biodiversity and the ability of soils to retain water.

Cultural heritage. Ways in which compaction influences cultural heritage include recreational activities where poor plant growth or waterlogging adversely affect sports pitches or footpath quality and through influences on biodiversity e.g. affecting botany (need to maintain specific conditions), birdwatching. Preservation of archaeological features may also require maintenance of specific water levels or soil conditions.

Ecosystem support. The impact of compaction on soil structure will affect soil biota, plant species (natural vegetation and weeds in agriculture), and other organisms higher up the food chain. Soil dwellers are directly affected by compaction. Compacted soils can also influence bird feeding and ground-nesting behaviour.

Environmental interactions. The influence of compaction on water holding capacity is a key feature in relation to environmental interactions. The decrease in hydraulic conductivity caused by soil compaction impedes drainage from land due to the reduction of the soil's capacity to store water, potentially resulting in flooding. Increased run-off caused by soil compaction can lead to greater soil erosion, and losses of sediments and nutrients. Compaction can also provide the conditions necessary for wind erosion to occur. Nitrous oxide and methane production are influenced heavily by soil pore structure and reduced aeration through compaction can result in increases in both of these greenhouse gases. Where plant nutrient uptake is reduced by poor growth, nutrients become subject to greater loss by leaching or in gaseous forms, with resulting downstream pollution costs.

Biomass production. Crop/tree/plant biomass production is influenced both directly and indirectly by compaction although susceptibility varies between species. Root growth will be directly affected by increased mechanical impedance, this can result in poor exploitation of the soil volume and thus lower nutrient uptake and consequently yield. However, indirect effects through the creation of anaerobic zones on soil micro-organisms and important nutrient release process such as mineralisation of nitrogen are also significant. Waterlogging or drought may also favour the survival of plant pathogens in the root zone. Thus compaction can result in the need for extra fertiliser or agrochemicals and thus increased energy use in agriculture. Livestock production and health can also be influenced by poor growth and nutritional quality of fodder species caused by compaction. Survival of livestock pathogens in soils will also be changed e.g. influence of water on liverfluke survival.

c) Costs

Note that actual expenditures of mitigating compaction on agricultural land and a differentiated approach (taking into account different soil types, land uses and management regimes) to estimating the impact of compaction on yield are needed to avoid double counting between these categories. Extrapolation from a smaller set of farm yield and expenditure data is not advised.

Table 11 *Overview of economic impact categories for Scotland associated with compaction*

No	Imp. cat.[5]		ES[1]	SF[2]	Impact[3]	Data Status[4]
		On-site costs				
6.1	PC	Compaction affects biophysical properties of soil with adverse impacts on *agricultural productivity* (e.g. due to reduced infiltration, root depth; reduced plant health resulting in greater susceptibility to disease)	P	P	**-***	Y
6.2	MC	Cost of measures to *prevent compaction or restore the physical (and biological) soil structure* in compacted soil	P	P	*-**	Y
6.3	MC	*Increased nutrient inputs* to counter reduced productivity	P	P	*-**	Y
		Off-site costs				
6.4	SC	*Increased surface run-off* due to reduced water infiltration capacity can result in higher risk of flooding, soil erosion and related water pollution	F, B, W	W, B, F	*-**	N
6.5	SC	Reduced water infiltration can affect the *replenishment of groundwater aquifers* (long-term effect)	W	W	*-**	N
6.6	SC	Anaerobic conditions due to wetter soils can result in *increasing levels of N_2O emissions* with adverse impacts on climate change	A	A	*-***	N
6.7	DC	Costs associated with measures to manage increased surface run-off	F	W, F	*-**	N
6.8	NC	Impacts on landscape values; biodiversity etc.	L, C	L, C	*-**	N

[1] Ecosystem services related to economic impact category (Section 3.5); [2] Soil functions affected (Section 3.6); [3] Impact assessment for Scotland (see Section 3.7) * low, ** medium, *** high; [4] Economic estimates related to the impact categories (Y Yes; N No) are available in Görlach et al. (2004), ADAS (2006) and Defra (2009); [5] Economic impact categories as defined in Section 3.4.

d) Examples that could be applicable to Scotland:

Impact No	Examples
6.3	Remediation to improve soil structure through fertiliser or incorporation of soil organic matter
6.2	New technology to reduce compaction of traffic (e.g. GPS systems)
6.6	Increased GHG emissions from compacted vulnerable soils

5. REVIEW OF SOCIO-ECONOMIC DATA FOR SOIL EROSION

5.1 Introduction

In this section we review the available estimates for the socio-economic impacts of soil erosion. We opted for the more detailed consideration of this single pressure as it has a range of impacts both on and off-site / private and social. Soil erosion also has a number of environmental impacts including changes to water quality and loss of soil organic matter with consequent carbon emissions. A number of studies have attempted to estimate the costs of soil erosion in different countries across the world. These have primarily considered the private on-site costs (PC) and social off-site costs (SC) with only a few studies considering the on-site mitigation (MC) and off-site defensive expenditures (DC). In this section we will review the nature of the cost estimates derived by these studies before assessing their transferability to Scotland and identifying data needs.

5.2 Private on-site costs

Review of existing literature

The available estimates of economic values with the PC category refer to the impacts of soil erosion on agricultural production. These studies typically relate the loss of soil through erosion on a per hectare basis to the consequent loss of crop production. The value of the lost production is then used to estimate the private cost of erosion. These estimates might also be extended to include the value of production inputs (fertiliser, pesticides) also lost due to erosion, although the extent to which these should be considered depends on the point in the production cycle that the erosion incident occurred. Similarly the gross margin for the crop could be used to capture the costs of both lost output and inputs.

Table 12 summarises the studies of PC estimates identified by Görlach *et al*. (2004). The values were converted into common €2003 values from the original years and currencies; we have converted and rebased these to £2009 values. Cost estimates are typically given in per hectare per annum terms and range from £0.10 to £38.19. The main drivers of these values are the rate of erosion (e.g. soil loss per ha) and the value of the crop planted in the ground. For example, Evans (1996, also summarised by Darmendrail *et al*., 2004) estimates losses for both land planted with winter wheat (lower value) and sugar beat (high value).

Table 12 *Summary of on-site (private) soil erosion cost estimates*

Author	Year	Region/country	Cost units	Mean (£2009)[a]	Comments
Darmendrail *et al*.	2004	England/Wales	ha/yr	1.55	Lost inputs and outputs
Darmendrail *et al*.	2004	Pays de Caux/France	ha/yr	9.59	
Darmendrail *et al*.	2004	Lauragais/France	ha/yr	21.57	
Hartridge and Pearce	2001	England/Wales	ha (NPV)	5.19	Nationwide average
Evans	1996	England/Wales	ha/yr	0.33	Lost output
Riksen & De Graaff	2001	Breckland/England	ha/yr	23.05	Wind erosion, with conservation measures
Riksen & De Graaff	2001	Breckland/England	ha/yr	38.19	Wind erosion, no conservation measures
Xu and Prato	1995	US	ha/yr	0.10	Erosion rate 2 t/ha/yr
Xu and Prato	1995	US	ha/yr	0.16	Erosion rate 3 t/ha/yr
Xu and Prato	1995	US	ha/yr	0.21	Erosion rate 4 t/ha/yr
Xu and Prato	1995	US	ha/yr	0.25	Erosion rate 5 t/ha/yr
den Biggelaar *et al*.	2001	US	ha/yr	0.28	Nationwide average
Crosson	1997	US	ha/yr	0.41	Nationwide average
Eastwood *et al*.	2000	New Zealand	ha/yr	0.82	Farm infrastructure damage
Hopkins *et al*.	2001	US	ha/yr	1.01	
Mallawaarachchi	1993	NSW/Australia	ha	3.60	
Eastwood *et al*.	2000	New Zealand	ha/yr	4.13	Lost output
Science Council of Canada	1986	Canada	ha/yr	5.75	

Source: adapted from Görlach *et al*. (2004)
[a] Mean soil erosion costs initially quoted in € 2003 in Görlach *et al*., these were converted to £2003 using average 2003 £/€ exchange rate (0.692) and deflated to £2009 values using UK GDP deflator (0.866).

Transferability of data to Scotland

The context specific nature of the PC estimates means that direct transfer to Scotland may not be valid beyond giving the broad range of potential values as summarised in Table 12. These could be applied to an estimate of the number of hectares of land in Scotland subject to, or at risk from soil erosion. The issues that create the problems in transferring private cost estimates to Scotland include:

- Differences in soil erosion rates and frequencies;
- Differences in soil types;
- Crop type, some may not be relevant to Scotland;
- Crop yield as affected by environmental conditions and year of study which reflects trends in yield over time;
- Crop price, this may be related to crop attributes (quality) or year of study (reflecting fluctuations in market prices); and
- Input prices, these will vary according to the system being used or year of study.

If relevant Scottish soil erosion rates can be estimated and linked to land use then private costs could be estimated in relatively straightforward manner. For example, Evans (1996) in a study of England and Wales derived equations from observations that can be used to link know soil volume losses (m^3/ha) with the percentage of land area that is lost to erosion[12]. Two such functions are derived and are illustrated in Figure 3. Ultimately the use of such relationships, although based on observation, will require assumptions to be made, for example concerning the depth of soil which has been eroded.

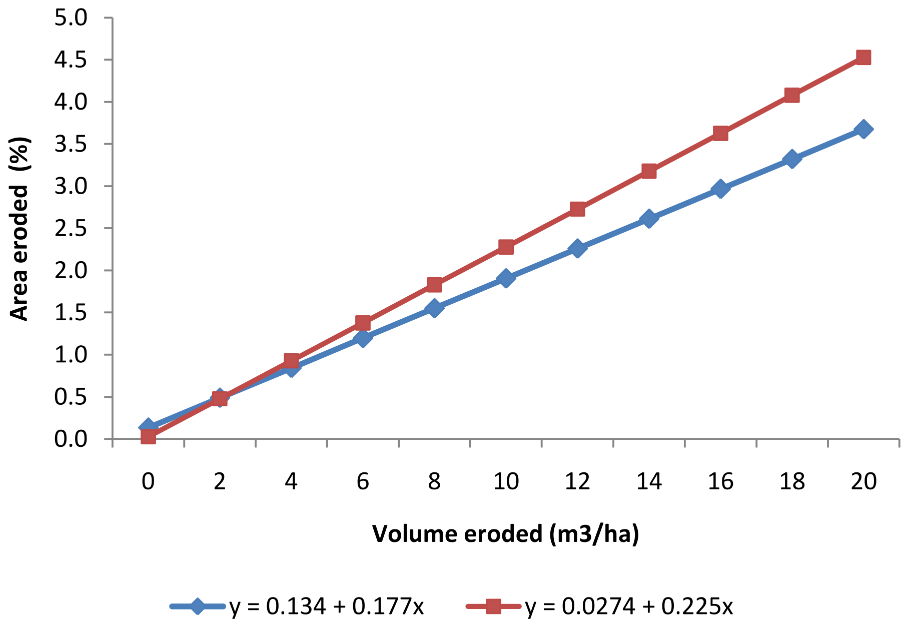

Figure 3 *Estimated relationships between volume and area eroded. Source: Evans (1996)*

[12] Where soil erosion is measured in tonnes/ha available bulk density coefficients can be used to determine volume of soil lost.

5.3 Mitigation costs

Review of existing literature

Mitigation costs arise from expenditures made to limit the impact of soil erosion and to prevent further erosion. Mitigation actions might include hedge planting to reduce wind erosion and increased nutrient inputs to replace those lost through erosion. Table 13 summarises the values for mitigation costs. As noted by Görlach *et al*. (2004) few studies reflect this cost category so there are a wide range of values which reflect individual contexts. Further, it is possible that erosion mitigation such as hedgerows have been installed for different reasons, with erosion mitigation being an unmeasured ancillary benefit.

Table 13 *Summary of on-site (private) soil erosion mitigation cost estimates*

Author	Year	Region/country	Cost unit	Mean (£2009)[a]	Comments
Alcock	1980	Queensland/Australia	ha/yr	1.31	
King and Sinden	1988	NSW/Australia	ha/yr	2.07	
Ehrnsberger	2000	Bavaria/Germany	ha/yr	49.13	Related to 8t/ha/yr eroded

Source: adapted from Görlach *et al*. (2004). [a] Mean soil erosion costs initially quoted in € 2003 in Görlach *et al*., these were converted to £2003 using average 2003 £/€ exchange rate (0.692) and deflated to £2009 values using UK GDP deflator (0.866).

Transferability of data to Scotland

Given the paucity of studies, and the dependency on context suggested by the range of values we would not recommend transferring these values to a Scottish context. As these are the lowest of the estimated values (see Table 16 below) the omission of this cost category from future Scottish estimates may not be significant.

5.4 Social costs

Review of existing literature

This is the largest category of soil costs in value terms and covers a range of potential impacts. Table 14 summarises the estimates for the different types of social costs of soil erosion on a per hectare basis. The largest social cost impact relates to soil organic matter losses and climate change impacts. The value of £36 per hectare represents soil organic matter and subsequent losses of CO_2 for arable land would give an aggregate annual value of £60.5m (£2009) based on estimated OM loss rates of 1.7% from 20% of arable land between 1980 and 1996.

The second largest social cost category from soil erosion is the cost of water treatment; this is primarily the cost of sediment removal from drinking water supplies. Caution is required with such estimates as they may reflect natural and on going sediment transport rather discrete soil erosion incidents that arise from land management. Part of the cost is also specifically incurred to remove phosphates that are attached to sediment. The distinction between social costs incurred through either natural processes or management decisions is important in terms of determining policy responses. In the latter case we would argue that an externality exists and that regulation (for example through cross-compliance measures) is required to internalise soil erosion impacts. In the case of natural processes management decisions are not resulting in an externality, but there might be the potential for management to moderate those process, consequently incentive payments might be appropriate (e.g. SRDP Land Manager Options). Table 15 presents aggregate estimates of the social costs of soil erosion in England and Wales based on estimates from Evans (1996) and Pretty *et al* (2000) as indication of the total scale of social costs. The largest cost item is water treatment, however this is certainly an over estimation of erosion related costs as it includes nutrient and pesticide removal costs.

Transferability of data to Scotland

The transferability of the social costs estimates of soil erosion to Scotland will be affected by the context of those estimates. The largest (per hectare) value was for loss of soil organic matter and CO_2 emissions, this will depend on erosion rates and soil organic matter content of the soils being eroded. The value applied to CO_2 emissions is also important; the social cost of carbon (see Defra, 2007) sets values for emissions in terms of the year the emission occurs, with cost per tonne increasing over time. This reflects the higher marginal damage of a tonne of CO_2e[13] as it adds to existing atmospheric concentrations. Consequently, when valuing these impacts we need to know both the size of the emission and when it occurred.

The social cost of carbon (SCC) is derived by estimating the global damage due to each additional tonne of CO_2e emitted from a change in activity or practice (e.g. land use or change or management changes) over the lifetime of CO_2 in the atmosphere. The shadow price of carbon (SPC) is a development of the SCC that takes into account both the likely damage and marginal abatement costs of achieving greenhouse gas stabilisation within the range of 450-550 parts per million CO_2e. More recent UK government guidance (DECC, 2009) has introduced a ‘target consistent’ approach based on the abatement cost of achieving UK emissions reduction targets. In the new approach carbon values are derived for traded and non-traded sectors that are to be used in policy appraisal. The traded sector refers to industrial sectors within carbon trading systems such as the ETS or any future additional schemes. For 2010 the traded sector had a central carbon value estimate of £22 per tonne CO_2e, this compares to £52 per tonne for the non-traded sector; the 2010 SCC damage cost is £28 per tonne. By 2030 the traded and non-traded carbon values are scheduled to converge at £70 per tonne. The more recent values are intended for policy appraisal purposes and we recommend continued use of the SCC when considering the respective damage or benefits of soil carbon loss or sequestration.

The costs of water treatment due to soil erosion will also depend on the rates of erosion and the land use patterns in catchments where drinking water is abstracted. For example, greater abstraction from upland reservoirs relative to river abstraction in catchments where arable farming predominates is likely to incur lower erosion related treatment costs.

Where transfers of soil related costs have been made to Scotland these have been on the basis of rough apportionments from England and Wales estimates and relative agricultural activity. For example the Environmental Accounts for Agriculture (Jacobs and SAC, 2008) as further developed by Defra[14] take soil erosion costs (based on channel dredging costs in England) and apply these to Scotland on the basis of the relative area of arable land; this calculation gave a damage cost estimate for Scotland of £1.3m in 2008. Drinking water treatment costs, not all of which would be attributable to soil erosion, were estimated by Jacobs and SAC (2008) as £19.8m (2008). These transfers did not attempt to determine the extent to which the cost incurring activities (channel dredging and relevant water treatment costs) arise in Scotland.

CO_2e[13] Carbon dioxide equivalents

[14] Updates to the environmental accounts undertaken by Defra can be found at: http://www.defra.gov.uk/evidence/economics/foodfarm/reports/envacc/index.htm (accessed 24/5/10)

Table 14 *Summary of off-site (public) soil erosion cost estimates*

Author	Year	Region/country	Cost unit	Mean (£2009)[a]	Adj. mean (£2009)[a]	Cost category
Clark *et al* Darmendrail *et al* Eastwood *et al* Ehrnsberger Fox & Dickson	1985 2004 2000 2000 1988	US England/Wales/France New Zealand Germany US	ha	19.32	6.86	Cost of sediment removal from ditches and waterways
Darmendrail *et al* Eastwood *et al* Evans Pretty *et al*	2004 2000 2004 2000	England/Wales/France New Zealand England/Wales UK	ha	2.75	2.75	Infrastructure damage
Clark *et al* Darmendrail *et al* Eastwood *et al* Evans Pretty *et al*	1985 2004 2000 1996 2000	US England/Wales/France New Zealand England/Wales UK	ha	24.12	24.12	Water treatment
Eastwood *et al* Evans Evans	2000 2004 1996	New Zealand England/Wales England/Wales	ha	0.81	0.81	Property damage
Clark *et al* Eastwood *et al*	1985 2000	US New Zealand	ha	5.09	5.09	Flood damage
Clark *et al* Darmendrail *et al*	1985 2004	US England/Wales/France	ha	11.85	11.85	Recreation (e.g. angling)
Pretty *et al*	2000	UK	ha	36.02		OM loss/climate change
Mallawaarachchi	1993	NSW/Australia	ha	1.35		2nd order economic effects (income losses)

Source: adapted from Görlach *et al*. (2004).[a] Mean soil erosion costs initially quoted in € 2003 in Görlach *et al*., these were converted to £2003 using average 2003 £/€ exchange rate (0.692) and deflated to £2009 values using UK GDP deflator (0.866).

Table 15 *Estimated aggregate social costs of soil erosion for England and Wales*

Cost type	Aggregate cost (m£2009)
Damage to roads, ditches and property	3.36
Traffic disruption or accidents caused by flooding	0.10
Water pollution (cost of removing nutrients, pesticides, sediment and colour)	245.56
Damage to stream channels	6.61
Damage to footpaths	0.92
Indirect damage to fisheries and fishing	20.87
Monitoring erosion	7.21
OM loss/climate change [a]	60.51
Total offsite costs	**345.15**

Source: Evans (1996) and Pretty *et al* (2000). [a] UK estimate

5.5 Defensive expenditure

Review of existing literature

This cost category includes expenditure on measures to reduce the off-site impacts of soil erosion, for example public subsidies to farmers to plant vegetation strips to capture sediment. Care is therefore necessary as there is likely to be some private benefit from such measures. Görlach *et al*. (2004) identified four studies that estimated values for off-site defensive expenditure to counter soil erosion impacts. They estimate the average (unadjusted) cost of defensive expenditures to be £15.50/ha/annum however it is not clear how this figure is estimated from the details of the studies quoted. The studies identified are for France, Spain, Mexico and New Zealand.

Transferability of data to Scotland

In common with the other cost categories it is our view that the estimate for defensive expenditure is context specific and we could not transfer this to Scotland with any level of confidence.

5.6 Data needs and gaps for Scotland

The review of existing cost estimates for soil erosion has highlight the context specific nature of many of the impacts both in terms of soil types, land use (e.g. crop type) and the use to which we put environmental resources that might be affected by soil erosion (e.g. water abstraction, navigation). This greatly reduces the confidence with which we can transfer these values to Scotland either directly or with some adjustment for land use or land area.

Private Costs. Accurate estimation of private on-site costs will require data on both rates of soil erosion and land use in terms of crops planted and management techniques employed (e.g. nutrient and crop protection timings). This would be a demanding task to undertake across Scotland, so selecting a small number of representative sites would be recommended.

Social costs. The loss of soil organic matter and consequent CO_2 emissions will require estimates of physical losses of soil organic matter in Scotland. For commonality with other estimates of climate change impacts, the relevant shadow price of carbon should be used. Cost estimates for removal of sediments from drinking water in Scotland are not readily available and would be necessary to obtain an accurate estimate of that soil erosion impact. UK data on infrastructure costs arise mainly from Evans (1996) and Pretty *et al*. (2000) and are specific to England. Cost estimates for activities such as clearing soil from roads in Scotland should be sought from local authorities covering areas where there is a known risk of soil erosion.

An important element of the social cost of soil erosion has been omitted in terms of the general reduction in water quality due to sedimentation. Görlach *et al*. (2004) classify this as non-user cost (NC) as the effects of social welfare are largely indirect (e.g. loss of welfare from knowing a state of poor environmental quality exists). However, it can in practice be difficult to disentangle the values held by users (e.g. recreational users) and non-users due to the methods used to estimate values. Estimates have been made for the value of different water quality states in Scotland (see Lago and Glenk, 2008) and in the England (e.g. Geogiou, 2000). Adjustments could potentially be made to these value estimates to reflect the changes in water quality status that arise from levels of soil erosion experienced in Scotland.

Mitigation and defensive costs. These two categories consider similar types of measures to reduce the impact of soil erosion, with the costs and benefits from action accruing to either private land managers or wider society. There is the potential for double counting here as private costs may achieve both private and social benefits and vice versa. It is also possible for soil erosion mitigation to arise as ancillary benefit of actions undertaken for different purposes such as hedgerow planting for landscape benefits or uncultivated field boundaries for habitat or water quality benefits. An estimate of these costs in Scotland could be obtained by surveying farmers or farm advisors to estimate private actions (e.g. within a sample of representative catchments) and through auditing policies such as the SRDP for measures that might mitigate both the private and social impacts of soil erosion.

5.7 Summary

Table 16 below summarises the estimates for each of these categories as reported by Görlach et al. (2004) and gives a intermediate estimate together with upper and lower bounds based on the range of studies identified for each cost category. The estimates suggest that off-site costs are the highest with intermediate values of £51.47 per hectare for social costs and £15.50 per hectare for defensive expenditure, these compare to £4.53 per hectare for private costs and £1.71 per hectare for mitigation costs. Care should be taken when aggregating these per hectare costs to larger scales, as the true form of the underlying cost functions is unknown and the values might either not reflect the 'average' cost per hectare or the function may be non-linear or subject to discontinuities and thresholds. Linked to this is potential bias from extreme values. For example, erosion events may have been studied because of their serious nature in a particular context or place which reduces their more general applicability.

Table 16 *Summary of soil erosion cost estimates across cost categories*

	Cost category (£2009/ha)[a]			
	Private costs (PC)	Mitigation costs (MC)	Social costs (SC)	Defensive expenditure (DC)
Upper bound estimate (unadjusted mean)	6.63	17.52	101.31	15.50
Intermediate estimate (adjusted mean)[b]	4.53	1.71	51.47	15.50
Lower bound estimate	0.31	0.00	12.84	0.00

Source: adapted from Görlach *et al*. (2004). [a] Costs initially quoted in € 2003 in Görlach *et al*., these were converted to £2003 using average 2003 £/€ exchange rate (0.692) and deflated to £2009 values using UK GDP deflator (0.866). [b] Lowest and highest values excluded from calculation of mean.

6. DISCUSSION

This report provides an overview of socio-economic impacts of environmental change that could affect soils and soil functions. The report is framed around the State of Scotland's Soils report, which organises impacts around key pressures to the soil resource. The distinction of soil related issues according to the different pressures is a first step in synthesising the vast body of knowledge available on biophysical impacts of environmental change related to soil. Although the pressures are all related to various policies and regulations, the report does, however, carry little notion of specific management or policy options impacting on soil, which would be an alternative and a more useful approach to data collection from a socio-economic point of view. An alternative to determining which pressure would have the most severe impacts on soils / soil functions would be to evaluate alternative management options aimed at reducing soil degradation and ultimately prioritise them according to social desirability, taking into account all private and social costs and benefits associated with these options.

Policy or management options may be associated with several pressures at the same time. Treating each pressure separately can therefore make it difficult to resolve the problem of socio-economic impacts that overlap between pressures. Due to interactions between soil pressures, summing up the total cost estimates of all soil threats would result in an overestimate of the total cost of soil degradation for Scotland due to double counting. It would be useful to specifically address the linkages between pressures from a socio-economic perspective in a future piece of work. Such work could also identify positive and negative feedback loops between pressures. We have tried to briefly touch upon interactions between pressures, and discussed problems for economic assessment of changes to soil, for example regarding the risk of double counting, issues regarding the time scale including longer-term impacts and threshold effects, and in particular difficulties associated with exactly determining and separating the contribution of soil as opposed to other elements of the natural system in the provision of ecosystem services.

Despite these concerns, we have been able to present a comprehensive overview of socio-economic impacts associated with each soil pressure. The large number of impact categories and the variety of affected soil functions and ecosystem services reflects the integrative and essential role that soil plays in sustaining human activities and ecosystems. At the same time, and possibly in part due to the difficulties in relating economic impacts specifically to soil, the large collection of impacts illustrates that large knowledge gaps exist in appraising the socio-economic impacts of pressures on soil.

These data gaps made it difficult to compare the magnitude of socio-economic impacts *between* pressures, but also to evaluate the relative impacts of categories for *each* pressure. This contributes to large uncertainty regarding the magnitude of impacts for many pressures. The assessment was also complicated by a lack of processed information on the spatial distribution and nature of biophysical impacts across Scotland. In some cases, data may actually be available to allow a more detailed assessment of the Scottish situation – our assessment of data availability in the tables (Yes or No) referred only to a limited set of UK and European review exercises combined with our knowledge. The uncertainty of impacts as expressed in this report hence confounds uncertainty about the *state of* available information with uncertainty associated with biophysical and socio-economic impacts about which information is already available.

The uncertainty about which information is available may be reduced. Some of the data gaps across the different pressures may be addressed more easily than others. Future work could be based on the table in Appendix B. This table could be amended to encompass the impact categories identified in this report, and screened according to the possibilities of deriving the relevant biophysical and related socio-economic indicators necessary for a detailed assessment of impacts for Scotland. Because of the huge scope of such a project, the approach could be tested for individual pressures before being extended to all pressures.

Beyond listing the theoretically possible impact categories, we provided a short list of examples that make reference to real issues in Scotland. It would be useful to extend these lists, translating the generic impact categories into real-world examples and detailing the examples with information on, for example, the state of knowledge, the spatial distribution and magnitude of biophysical impacts, the actors involved and the availability of related information on costs and benefits. By doing so, a suite of case study examples could be developed and explored further if policy needs arose.

In the second part of the report, we addressed a more detailed investigation of socio-economic impacts associated with one of the pressures – soil erosion. There is a wide range of estimates for the different cost categories for soil erosion that have been drawn from a range of countries over a number of years. These estimates are often context dependent and this reduces the confidence with which they can be transferred to Scotland beyond giving a high level estimate of the potential range of costs. We recommend that on-site (private and mitigation) costs estimates for Scotland could be obtained by a case study approach in small number of representative catchments where there is an identified risk of soil erosion. Social cost estimates may be obtainable from relevant public bodies (e.g. Scottish Water, local authorities) to cover impacts such as drinking water treatment and removal of eroded soils from roads and ditches. The water quality impact of soil erosion, including non-use values, could be obtained by adjusting values from existing stated preference studies to account for the impact of soil erosion (e.g. suspended solids) on water quality.

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GLOSSARY

Term	Definition for this report
Benefit transfer	The transfer of existing valuation estimates from one or more 'study sites' to a new 'policy site'. Values may be adjusted to reflect both environmental and socio-economic differences between study and policy sites. Benefit transfer seeks to avoid the costs and time requirements of original valuation studies.
Carbon dioxide equivalent	Common metric by which emissions of different greenhouse gases can be directly compared following adjustment for their different warming potentials relative to CO_2. Expressed as CO_2e or CO_2eq.
Choice experiment	An economic valuation method in which survey respondents are asked to make choices between different bundles of environmental or policy attributes together with an associated price. The value of different levels of environmental or policy provision are estimated from the choice made.
Contamination	This is the presence of a substance where it should not be or at concentrations above background.
Contingent valuation	An economic valuation method in which survey respondents are asked to state their willingness to pay or accept (e.g. additional taxes) for a stated environmental change.
Counterfactual	This refers to the alternative scenario to that being valued. This may reflect the current situation (status quo); current trends; or no provision of a good or service. Valuations can only be made for changes relative to a defined counterfactual
Defensive costs	Social (off-site) costs incurred for measures to mitigate the damage caused by soil degradation, e.g. additional drainage and sediment traps.
Direct costs	Private (on-site) costs incurred for damage caused by soil degradation, e.g. loss of crop yield.
Ecosystem services	Ecosystem services are the benefits that people obtain from ecosystems. They reflect a range of different endpoints from the functioning of managed and natural ecosystems that contribute to human well-being.
Hedonic price method	An economic valuation method that estimates the value of environmental amenity or disamenity through its effect on property values.
Maximum willingness to pay	This is the amount of money an individual would give up in exchange for improvements, e.g. in environmental conditions, to remain on the same utility level as before the exchange took place. In other words, it is the amount of money an individual would part with to be as well off after a change (in environmental conditions) than before.
Mitigation costs	Private (on-site) costs incurred for measures that reduce the impact of soil degradation, e.g. sediment traps, features to reduce wind erosion.
Non-use costs	Social (off-site) costs incurred from the loss of non-use benefits due to soil degradation, e.g. the existence value of high water quality.
Pollution	The introduction of contaminants into an environment that causes instability, disorder or harm to ecosystems.
Primary value	Otherwise known as "glue value". This is not associated with use value to humans (Turner et al. 1994). It is perceived as an eco-centric value which is inherent to an ecosystem's self organizing capacity and in determining ecosystem resilience. It is independent of human preferences, and irrespective of human desires or will. "[The primary value] ... is the source of other, so called exported or secondary values of the ecosystem. The secondary values therefore depend on the continuous preservation of the 'ecosystem health'" (Fromm 2000).
Revealed preference	Economic valuation methods that infer value from observing behaviour relating to the environmental good of interest, e.g. hedonic pricing and travel cost.
Social costs	Social (off-site) costs incurred for damage caused by soil degradation, e.g. drinking water treatment, dredging of river channels, removal of eroded soil from roads.
Social cost of carbon (SCC)	This is directly derived from estimates of the global damage due to an additional tonne of carbon dioxide equivalent being emitted over its lifetime in the atmosphere.
Soil functions	Soils can be defined by their inherent capacity to deliver a range of functions and that degradation of inherent soil properties and processes will compromise the delivery of these functions with the sustainable use of soils only possible by a temporal and/or spatial "harmonisation" in soil functions (Blum, 2005).
Soil organic matter	Soil organic matter is a generic term for all carbon-containing material in the soil that derives from living organisms. It affects several critical soil functions and has a fundamental role in soil health.
Soil	Soil occurs on the land surface, is comprised of solids (minerals and soil organic matter), liquids and gases and is a natural medium for plant growth. Soil develops over time from the genetic, environmental and geological factors of climate, organisms, relief and parent material over a period of time.
Stated preference	Economic valuation methods that determine values from responses to hypothetical policy or payment scenarios, e.g. contingent valuation and choice experiments.
Threshold	A critical point or value at which a detrimental response will occur within an ecosystem. This term is adapted from dose-response relationships when harm is triggered by pollutants at critical levels.
Travel cost method	An economic valuation that infers values for a (typically recreational) site from the time and expense incurred by visitors in visiting the site.
Willingness-to-pay (WTP)	WTP is the maximum amount in monetary terms that an individual would be willing to pay in exchange for consuming a good, willingness-to-accept is the amount an individual is willing to accept in exchange for forgoing or abandoning the consumption of a good.

APPENDIX A AN EXAMPLE LINKING SOIL DEGRADATION, SOIL FUNCTIONS AND COSTS THROUGH THE CHARACTERISATION AND QUANTIFICATION OF INDICATORS FOR SOIL PRESSURES *(developed from Görlach et al., 2004).*

Pressure	Soil Function affected	(A) EXTENT of soil quality / degradation indicator	Unit	(B) Status of soil quality degradation indicator	Unit	Economic indicator	Unit	Type
Decline in soil organic matter	Environmental interactions	Total carbon (C) contained in soil by land use sector	t/ha	Total soil C stock	kg/m^3	Avoided climate change effects		
	Environmental interactions	Reduced GHG emissions by land use sector		IPCC GHG emissions		Avoided climate change effects		
	Food and fibre production	Area with SOC below critical SFSS thresholds	ha/yr	Topsoil C	g/kg	Cost of additional fertiliser inputs and costs of soil structural management practices		
	Supporting ecological habitats and biodiversity	Area with SOC below critical SFSS thresholds (woodlands / grassland)	ha/yr	Topsoil C	g/kg	% Cost of conservation / mitigation measures		
Sealing	Food and fibre production	Loss in agricultural land due to construction	ha/yr	None yet defined		Crop yield losses	£	Private
	Food and fibre production	Loss in forestry land due to construction	ha/yr	None yet defined		Crop yield losses	£	Private
	Supporting ecological habitats and biodiversity	Loss in semi-natural land due to construction	ha/yr	None yet defined		landscape / amenity values	£	
	Protection of cultural heritage	Area or number of lost archaeological remains	N or ha/yr	Presence of buried remains	N/ha			
Contamination	Food and fibre production	Area affected by elevated heavy metals above statutory soil thresholds (arable / grassland)	%/yr	Heavy metal levels (Zn, Cu, Ni, Cd) and / or rhizobium levels	mg/kg; mpn	Cost of additional fertiliser inputs or clover re-establishment	£	Mitigation
	Food and fibre production	Area affected by acidification (arable / grassland)	%/yr	Soil acidity and S status	pH units & mg/kg	Cost of liming and additional S		
	Food and fibre production	Area affected by eutrophication (arable / grassland)	%/yr	Nutrient status (N)	mg/kg	Cost of additional fertiliser inputs		
	Supporting ecological habitats and biodiversity	Area affected by eutrophication (semi-natural)	%/yr	Nutrient status (C/N or potentially mineralisable N)		Cost of conservation measures (e.g. additional biomass removal)		
	Environmental interactions	Waters receiving soil nutrients	?	Transfer of P and N to water sources?	ml/l	Installing buffer zones ; Off-site effects (areas affected, etc.)		
	Environmental interactions	Waters receiving dissolved organic carbon from soils	?	DOC in soil water chemistry?	ml/l	Off-site effects - water purification costs		

Cont. **APPENDIX A AN EXAMPLE LINKING SOIL DEGRADATION, SOIL FUNCTIONS AND COSTS THROUGH THE CHARACTERISATION AND QUANTIFICATION OF INDICATORS FOR SOIL PRESSURES** *(developed from Görlach et al., 2004).*

Pressure	Soil Function affected	(A) EXTENT of soil quality / degradation indicator	Unit	(B) Status of soil quality degradation indicator	Unit	Economic indicator	Unit	Type
"Loss" in biodiversity	Food and fibre production	Area at risk from loss in function of Rhizobium due to elevated heavy metals above statutory soil thresholds (arable / grassland)	%/yr	Heavy metal levels (Zn, Cu, Ni, Cd) and / or rhizobium levels	mg/kg; mpn	Cost of additional fertiliser inputs or clover re-establishment	£	Mitigation
	Supporting ecological habitats and biodiversity	Areas where Large Blue Butterfly has been declared extinct	ha/yr	Occurrence of essential symbiotic ant species	+/-	% Cost of conservation / mitigation measures to restore any colonies		
Erosion and landslides	Food and fibre production	Area affected by erosion (arable / grassland)	%/yr	None yet defined		Crop yield losses	£/%	Private
	Food and fibre production	Agricultural area affected by erosion (arable / grassland)	%/yr	Nutrient status (N, P, K)	mg/kg	Cost of additional fertiliser inputs	£	Mitigation
	Food and fibre production	Area affected by erosion (forestry)	%/yr	None yet defined		Crop yield losses	£/%	Private
	Supporting ecological habitats and biodiversity	Area affected by erosion (semi-natural habitats)	%/yr	None yet defined		Cost of stabilisation / conservation measures	£	Mitigation
	Environmental interactions	Soil loss per year by erosion	t/ha/yr	Sediment loads in run-off		Off-site effects (siltation etc.)	£	Social
	Protection of cultural heritage	Area of recreation ground lost	ha/yr	Soil / land area	ha	(Educational? Lost revenue?)		
	Protection of cultural heritage	Area or number of lost archaeological remains	N or ha/yr	Presence of buried remains	N / ha	(Educational? Lost revenue?)		
Compaction	Food and fibre production	Agricultural area affected by floods	ha/yr	None yet defined		Crop yield losses	£	Private
	Food and fibre production	Area affected by different degrees of compaction	ha/yr	Topsoil density	kg/m^3	Crop and pasture losses; mechanical remediation and management costs	£	Defensive
	Environmental interactions	exceeding soils capacity to retain water	?	Catchment hydrographs?		Off-site effects (areas affected, etc.)		
	Environmental interactions	Area affected by different degrees of compaction	ha/yr	Topsoil density	kg/m^3	Off-site effects (areas affected, etc.)		