

National Soil Resources Institute

SOIL-BASED SERVICES IN THE BUILT ENVIRONMENT

A report prepared for the Department of Environment, Food and Rural Affairs

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Contents

Acknowledgements.....	2
Executive Summary.....	5
1. Introduction.....	9
1.1. Overview.....	9
2. Exploration and definition of soil functions in the built environment.....	10
2.1. Background.....	10
2.2. Factors controlling service delivery.....	11
3. Service components and capacity.....	14
3.1. Environmental services.....	14
3.1.1 Regulation.....	14
3.1.2 Maintenance (waste processing).....	18
3.2. Food and fibre production.....	18
3.3. Habitat and biodiversity.....	19
3.4. Cultural services.....	21
3.5. Platform.....	24
4. Valuation of soil services.....	25
4.1. Introduction.....	25
4.2. Holistic valuation.....	25
4.2.1 State indicators.....	27
4.3. Relationship to land values.....	28
5. Illustrative “story-lines”.....	30
5.1. Greenfield development.....	30
5.2. Sealing Gardens.....	31
6. Risk assessment of harm to soil in the built environment and impacts of this on soil-based services.....	32
6.1. Conceptual model.....	32
6.2. Types of harm to soil in the built environment.....	32
6.3. Types of hazard to soil in the built environment.....	33
6.4. Consequences of harm on capacity for soil-based services.....	35
6.5. Review of current practice and possible risk management options and guidance.....	38
6.5.1 Introduction.....	38
6.5.2 Sealing.....	38
6.5.3 Physical profile degradation.....	39
6.5.4 Chemical contamination.....	41
7. Conclusions.....	42
8. References.....	45

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Executive Summary

Background

Publication of the First Soil Action Plan for England in 2004 has drawn attention to the value that can be derived from the protection and appropriate management of the country's soil resources. This principle applies all soils equally including those in built environments which are the subject of this report.

Soil is valuable because it underpins both quality of life and biodiversity conservation. It does this by providing a range of services or functions which meet human needs and sustain natural systems. The principal of these are environmental regulation and environmental maintenance, food and fibre production, above and below ground habitat maintenance as support for biodiversity, protection of cultural services and provision of a platform for the built environment.

Soil is, in practical terms, a non-renewable resource which can be destroyed by construction. To help protect soils in the built environment, the services they can and do provide to both society and the environment need to be documented and explained. This report proposes a framework to help explain soil's services and functions within built environments and provides a literature-based review of those services, their current perceived value, and a risk assessment of the threats that may degrade them.

Soil service delivery

The range of services that soil provides in the built environment is the same as in any other environment, namely, environmental regulation, food and fibre production, waste management, support for habitats as a source of biodiversity, protection of cultural heritage, and platform provision for built infrastructure. However the relative mix and direct, or indirect, management to support those services differs from rural environments.

The physical condition of soil, which reflects past and current land use and management, exerts an over-arching control over biological activity in soil and through this on its capacity to deliver services. The general condition of the soil profile is an indicator of service capacity and may be assessed by considering the extent to which the natural profile remains intact or is degraded. The extent of soil sealing provides another indicator of the capacity for soil service delivery. Transfer of water and air to and from the atmosphere and soil is influenced by the permeability of the soil surface, which in turn depends on the extent of surface sealing by construction, paving or compaction. Natural variability in soil texture and chemical properties influences soil performance in the built environment even where the natural topography is obscured. This influence is often important even although it is secondary to sealing extent and profile condition.

Valuation of soil services

Little or no systematic assessment has been made of the social and economic values of soil in built environments. To achieve this, a holistic approach to soil evaluation is needed. Preliminary estimates from simply equating land area to current land 'asset' value suggest that the total value of ecosystem services for natural soils outside of built environments may be roughly equivalent to development land values.

Risk assessment of harm to soil

Actual and potential hazards to soils, and the harm they may cause, arise for a number of reasons: through Greenfield development, or through a lack of awareness of soil services when residents carry out 'improvements' such as the paving of patios and hard standing for cars. Greater housing densities and development within the current building line could increase pressure on public amenity areas, leading to soil compaction by increased trampling that compromises soil services. For each of these, and others, there is an inherent hazard, but much also depends on the awareness, understanding and competence of those involved.

Climate change represents a multi-dimensional hazard to soil-based services. It will affect the soil system itself, by altering especially the water regime and, as a result, the inherent capacity of the soil to deliver services. It will also change the demand for services both within the wider terrestrial system (*e.g.* via precipitation levels and distribution) and also due to changes in societal behaviours.

Risk management options and guidance

The planning process is able to refine risk assessments, but soil is not usually a material consideration. A range of restrictive planning measures, *e.g.* greenbelt designation, conservation areas and flood plain protection measures, remove the principal hazard leading to soil sealing, *i.e.* new construction, from designated parts of the country. This is also assisted by government commitments to using land efficiently, and encouraging re-development of Brownfield sites. Both planning law and building regulations have the potential to attenuate or concentrate soil sealing, by imposing building density targets and design principles. At present however, where these actions are taken, it is for reasons other than soil protection. A decision to accept soil sealing appears to be widespread, but the apparent lack of awareness of the value of services that are lost from soil when it is sealed, suggests poor risk assessment and management rather than a deliberate management decision. Under the planning regime, soil restoration requirements can be applied as a condition to planning consents. This is commonplace in relation to mineral extraction and is also applied to major construction projects, but is uncommon generally.

The lack of focus on soil resources in the development planning regime reflects the absence of specific policy guidance. Such guidance is essential if soil resources are to be afforded the same level of consideration as, for example, water. The First England Soil Action Plan identifies the development of guidance as an objective.

Building Regulations offer the potential to attenuate the risk of soil sealing during construction by specifying appropriate materials and construction methods. Regulations could specify use of porous surfaces for hard-standing or relative

proportions of paved and non-paved areas. Currently, there is no deliberate use of building regulations to control the extent of soil sealing in the built environment.

Physical profile degradation

Adoption of Soil Management Plans for development sites could refine, on a site-specific basis, the assessment of risk of physical soil profile degradation. Aspects to be considered, preferably in a site Soil Management Plan, are the removal of unused imported materials, the avoidance and mitigation of soil compaction, and the correct handling and placement of topsoil. Reduction in the use of aggregates and other materials, and restrictions to vehicle movement, could remove a hazard to the physical condition of soil or at least attenuate it. Site restoration after construction ought to be normal practice and is essential to the remediation of physical soil damage.

The actual risk of harm to soil on a construction site is affected by the awareness, understanding and competence of the site operator and his staff. If statutory regulations are introduced for site soil management, regulatory effort could be targeted towards with a poor track record, in a similar way to that employed under the Environment Agency's OPRA process.

Conclusions

In the built environment, land management will affect soil service capacity and delivery through surface sealing and soil profile modification.

Whilst it is possible that a change of land use from Greenfield to a built environment would result in a net gain in below-ground biodiversity, evidence of this is lacking. The general ecology of urban areas has been studied, but there is insufficient focus on soil itself as a habitat. Soil biodiversity *per se* in urban areas is a little examined topic requiring focused research effort.

A framework is needed to optimise the mix and levels of services remaining after land use change. This needs to be underpinned by a broader evidence base of service types and their value.

The value of soil in the built environment in relation to carbon sequestration is unknown but potentially great. Undoubtedly, net carbon sequestration by the soil resource changes as the proportion of built environments to Greenfield land increases. The precise impact of these changes at a local level is likely to depend on the specific pattern of land use change. There is no information on the net changes in carbon sequestration by soil following transfer into the built environment.

The proportion of sealed to unsealed soil surfaces largely determines the hydrology of the built environment, where unsealed soil represents valuable capacity for storm water management, and the sealing of soil surfaces reduces aquifer re-charge and available water for trees and amenity planting. Soil and vegetation can be actively managed to provide water management services in the context of Sustainable Urban Drainage Systems (SUDS). The efficacy of treatment of water pollutants depends on the soil type, its hydraulic properties and vegetation. Adversely, SUD systems may lead to an increase in soil contamination. There is a lack of advice on how to design and manage SUDS systems for the control of water quality.

Whilst much is known about the possible risks of soil contamination to human health, surface waters and groundwater, less is known about the effects of contamination on biodiversity, particularly within the soil itself. These considerations argue strongly for the application of the Precautionary Principle.

The built environment is an important place for buried archaeology. The potential for disturbance of artefacts is significant, both in Greenfield and Brownfield development. Better understanding and monitoring of soil conditions in the built environment has the potential to enhance archaeological conservation.

The evaluation of soil-based services in the built environment is incomplete. At best, their environmental value is only partially known, but in relation to their value to society and their direct and indirect economic benefits, these are unknown. The unrealised ecological value of passively managed soil in the built environment (e.g. road-side verges) may be substantial and offer potential for improving sustainability.

In line with the goals of sustainable development, an holistic approach to soil evaluation would seem essential. Preliminary estimates suggest that the total value of ecosystem services for natural soil that is not built on may equate to development land values.

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1. Introduction

The First Soil Action Plan for England: 2004-2006 was published in May 2004 and commits the Government and its partners to actions which will improve the protection and management of soil. DEFRA's vision is to ensure that England's soils will be protected and managed to optimise the varied services that soils perform for society, in keeping with the principles of sustainable development and on the basis of sound evidence.

The evidence base for management of soil/service/land use combinations in the built environment¹ is scattered and is not accessible in a collated form. There are no comprehensive national research programmes for soil in the built environment. Where they have been considered, the main emphasis has been on contaminated land and its remediation.

To support better soil management in the built environment, there is a need to review information on its properties, the services which it performs for society and to make an assessment of the threats to its condition.

1.1. Overview

This work explores and defines soil-based services in the built environment.

A review of current practice and possible risk management options is reported on and guidance on these is identified and reviewed for its general efficacy. The actual and potential threats to the services of soil in the built environment are summarised, and the potential management responses and the extent to which these are implemented at this time are discussed.

A framework for evaluating soil-based services from an economic, societal or environmental perspective is presented, along with a provisional indication of the value of soil in relation to current land value. The valuation that society places on these functions was not quantifiable due to a lack of available evidence.

In conclusion, critical knowledge gaps are highlighted with suggestions for future research.

¹ The working definition of the built environment used is that it is "land that is currently within the settlement boundaries of local spatial plans or which is identified for future development".

2. Exploration and definition of soil functions in the built environment

2.1. Background

Soil needs to be distinguished from land. Land is space within which different human activities and natural processes can take place. Soil is a living system which provides capacity within land to support these activities and processes. This report considers soil to be any soil that is natural, made-ground (imported materials) or modified (e.g. where subsoil remains after topsoil removal, or a topsoil is mixed during site development).

Effectively, natural soil is a non-renewable resource because it takes centuries to form completely. This natural resource is lost permanently when it is used as a primary material or destroyed by construction or mineral extraction. New soil can be engineered but a fully functional biological system will evolve only slowly.

Soil is valuable because it underpins both quality of life (social and economic) and biodiversity conservation. It does this by providing a range of services or functions which meet human needs (metaphysical as well as physical) and that sustain natural systems. These regulation, production, habitat, cognitive and platform ecosystem services (De Groot *et al.* 2002) or functions (Blum 1993) deliver environmental regulation and environmental maintenance (e.g. waste management), food and fibre production, above and below ground habitat maintenance as support for biodiversity, protection of cultural services and provide a platform for the built environment. The use of soil as a primary material is limited in the built environment.

Each service provided by soil is represented by a suite of component services (components) that reflect intrinsic soil characteristics and past and current soil management (Figure 1). For example, components of the environmental regulation service support transfer of water, air and materials to and from the atmosphere, surface water and groundwater. Human modification of soil changes its functional capacity *i.e.* its ability to deliver different services. This, together with changed demand arising from land use, alters the mix and levels of services that can be and are being delivered.

Intuitively, one might assume that when Greenfield land is developed there is a reduction in service capacity. However, there is lack of evidence to support or challenge this assumption. In agriculture and forestry, soil is managed to optimise yields of food or fibre products at the expense of other services. When this soil is taken into the built environment, the loss of food and fibre production could be offset by increased environmental and habitat support services from soil remaining outside building footprints. And when Brownfield land is re-developed there may be a loss or gain in service capacity depending on the mix of land-uses that are removed compared with those that are introduced.

Thus there is a need for a framework to optimise the mix and levels of soil-based services in the existing built environment and to inform retention of soil-based services during construction of new built environments on semi-natural, agricultural or forest land.

Figure 1 Relationship between sustainability goals and soil-based services (functions) and service components

GOALS	Human quality of life – social and economic Biodiversity conservation
SERVICES	Environmental (regulation) services, food and fibre production, waste management, support for habitats as a source of biodiversity, protection of cultural heritage (cognitive services), platform provision
SERVICE COMPONENTS	Examples: pollutant attenuation and degradation; horticulture; below-ground habitat; artefact preservation; building foundations

2.2. Factors controlling service delivery

Soil is a habitat for a great variety of ecological communities, which are the ultimate providers of soil-based services (Paul & Clarke 1996). The physical nature and distribution of pores and mineral aggregates and the arrangement of carbon and nutrients constitutes the architecture of this living system. Its nature influences the composition and activity of life in the soil. The consequence is that the physical condition of the soil exerts an over-arching control over biological activity therein, and hence on its capacity to deliver services (Young & Ritz, 2005).

There are a variety of engineered soils within the built environment, in addition to modified natural soils. Physical design and management is critical to their performance. Imported aggregates are compacted to create platforms for temporary buildings. Layers of different aggregates are used to create foundations for highway pavements that act as an effective platform while allowing necessary lateral drainage. Entirely artificial soil systems are created to support, for example, sports turf, green roofs and roof gardens. Soil is introduced and augmented in previously developed land to provide green areas for leisure and biodiversity.

Transfer of water and air to and from the atmosphere and soil is controlled by the permeability of the soil surface, which in turn depends on the extent of surface sealing by construction, paving or compaction. Thus the extent of sealing is an important factor controlling the performance of soil in the built environment. In particular, it controls the proportion of precipitation entering the soil profile and so the soil water regime. The importance of extent of sealing to the performance of soil is recognised widely (Van Camp *et al.* 2004).

Soil profiles in the built environment range from those that are little altered from their natural condition to those truncated by removal of surface horizons or those that are poorly developed in made ground. The condition of the soil profile affects the capacity for service delivery because pore volume and distribution determine rates of water transfer to groundwater and the movement of air to and from the soil surface.

Soil that has a well-developed structure in surface and sub-surface horizons is likely to have a higher water holding capacity and be more capable of supporting the free movement of water and air. By contrast a soil that is composed of bulky inorganic waste materials and which has been compacted to depth will perform less well. The physical condition of the soil profile is critical to the delivery of all services because it strongly influences the habitat conditions for life in soil. The general condition of the soil profile may be assessed by considering the extent to which the natural profile remains intact or is degraded. However, this degradation can arise in different ways, some of which are identified in Table 1.

Table 1 Types of physical soil profile degradation in the built environment

Degradation type	Description
Truncation	Removal of surface horizons
Burial	Addition of material on profile surface (<i>e.g.</i> imported soil, building rubble, etc)
Admixture	Addition of material by burial, backfilling of excavations etc
Compaction	Compaction at depth within the profile caused by surface pressure from <i>e.g.</i> vehicle traffic , material storage, etc

Physical soil conditions depend on past and current land use and management. The great variety of land uses in the built environment leads to variable sealing of the soil surface and different levels and forms of soil profile degradation. Figure 2 maps surface sealing and profile intactness for some different land uses. This mapping attempts to allocate a broad description of the soil condition that is anticipated to be most prevalent for a land use type. In reality, even small, individual land parcels may contain a variety of land uses and there may be a range of soil conditions within each of these. Nonetheless the simplified mapping illustrated in Figure 2 provides a useful framework for assessing generic relationships between land use and soil conditions relevant to service capacity. This leads to a simple typology as set out in Table 2.

Figure 2 Soil use in the built environment and associated soil condition

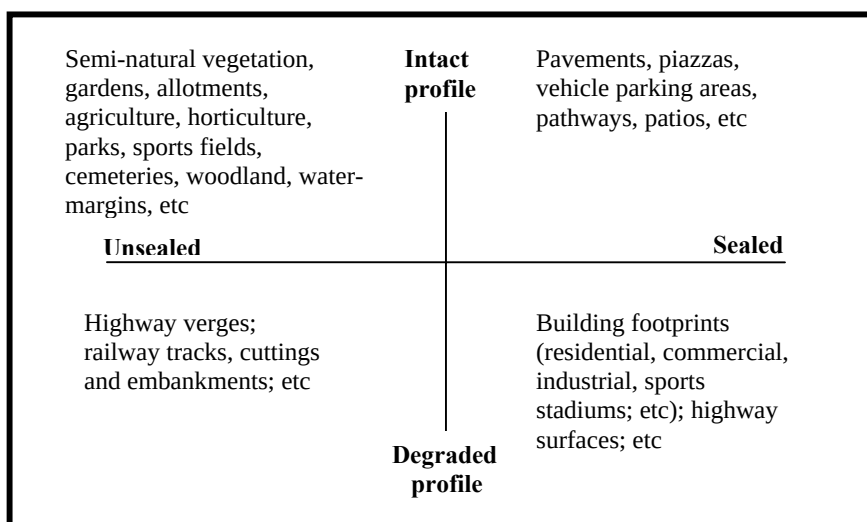


Table 2 Soil area use in the built environment and associated soil condition

Type	Soil area use	Soil condition
Sealed and degraded (SD)	Building footprints (residential, commercial, industrial, sports stadiums; etc); highway surfaces; etc	Sealed surface Severely degraded profile
Sealed sub-soils (SS)	Pavements, piazzas, vehicle parking areas, pathways, patios, etc	Sealed surface Moderately degraded profile (intact subsoil)
Unsealed modified (UM)	Highway verges; railway tracks, cuttings and embankments; etc Green roofs, roof gardens, raised beds, artificial sports areas, etc	Unsealed surface Modified or engineered profile
Unsealed and intact soil profile (UI)	Residual vegetation, gardens, allotments, residual agriculture and horticulture, parks, sports fields, cemetery gardens, woodland, water margins, etc	Unsealed surface Intact or moderately degraded soil profile (all soils are expected to be <i>physically</i> modified to a lesser or greater extent)

Natural variability in soil texture and chemical properties influences soil performance in the built environment even where the natural topography is obscured. This influence is often important even though it is secondary to sealing extent and profile condition. The presence of expansive clay minerals which cause shrinking and swelling of sub-soil may lead to foundation instability. The prevailing soil chemistry may determine above-ground vegetation type and, therefore, determines the nature of green spaces.

All soil in the built environment is degraded to some degree by pollution or past waste disposal or both. However, in most cases the level of any contamination is insufficient to represent a “significant possibility of significant harm” to important receptors, so the land is not designated as statutory contaminated land (DETR, 2000). However, contamination may still restrict the range of acceptable land uses. For example, whereas the level of soil contamination in a parcel of land used for car parking might be acceptable, this might not be so if the land use changes to residential with gardens or to food production. While much is known about the possible risks of soil contamination to human health, surface waters and groundwater (Hester & Harrison, 2001) less is known about the effects of contamination on biodiversity in the soil itself. These considerations argue strongly for application of the precautionary principle to the control of soil contamination.

3. Service components and capacity

3.1. Environmental services

3.1.1 Regulation

Introduction

Soil links the atmosphere to surface and ground waters, regulating rates of transfer of water, gases and sediments between environmental compartments. It also affects environmental quality, by attenuating and degrading pollutants. Table 3 provides a summary of the main soil-based environmental regulation services.

Table 3 Soil-based environmental (regulation) service components

Components	Relationship to physical condition	
	Sealing extent	Better profile condition
<u>Air</u>		
Sink for airborne pollutants	Negative	Positive
Carbon sequestration	Negative	Positive
Trace gas emission	Negative	Positive
<u>Surface water</u>		
Pollutant attenuation and degradation	Negative	Positive
Flow attenuation, including flood risk reduction	Negative	Positive
<u>Groundwater</u>		
Pollutant attenuation and degradation	Negative	Positive
Aquifer re-charge control	Negative	Positive

As these environmental regulation services depend on transfers of air and water to and from the soil profile, surface sealing (SD and SS) reduces and often eliminates them. An exception is those linked to lateral groundwater movement. In addition, sealing a soil may lock in carbon within the soil profile to ensure its continued sequestration. Regulation services are also reduced where the surface is not sealed but the profile is degraded (UM), by compaction or dilution of soil by inert materials such as building wastes. However, areas where the surface is not sealed and the soil profile is intact (UI) make a valuable contribution to environmental regulation. In addition, engineered soils may provide useful regulatory capacity depending on their design and construction.

Air quality

Unsealed soils (UI and UM) receive pollutants by wet and dry deposition. The main importance of soil to air quality is that it and soil-supported vegetation provide a sink for pollutants that would otherwise transfer to water or return to the atmosphere. Equally, soil-derived atmospheric dust can be a source of airborne pollution, where past activities have contaminated soil (Harrison *et al.*, 2001). Atmospheric pollutants found in finer, inspirable airborne particles may present risk to human health (DEFRA, 2002a; Enlgert, 2004; Harrison and Yin, 2000) and some of these may be soil-derived.

It is unusual to find buried topsoil in sealed environments due to its removal during construction. The majority of organic carbon, therefore, will have likely been removed before being sealed. The greatest change to subsoil organic carbon is probably through the lateral growth of roots of street trees that grow in tree wells or on adjacent unsealed land.

Levels of metals and other inorganic airborne pollutants in deposition have reduced in recent decades following tighter regulation of industrial emissions, the removal of lead from gasoline and a shift away from domestic coal burning (DEFRA, e-digest). Measurable fluxes of metals to soil surfaces persist, however, and new pollutants such as platinum from vehicle exhaust catalysts, emerge from time to time (Farago *et al.*, 1998).

Polycyclic aromatic hydrocarbons (PAH) derived from combustion processes are strongly absorbed to soil organic matter (Wilcke, 2000; Means *et al.*, 1980). Soil is a major sink for PAH and concentrations in “non-contaminated urban soils” outweigh rural sites by more than a factor of ten (Wild and Jones, 1995). Bacterial activity in soil can tolerate PAH. However, soils will range in their propensity to degrade PAH depending on the composition and quantity of bacteria. The degradation of soil profiles, or their sealing, will modify or remove the capacity of the environment to regulate PAH. Consequently, this would increase the potential deleterious effects on human health. Soil also acts as a sink for other persistent organic pollutants (POPs), including dioxins, furans and polychlorinated biphenyls (PCBs) (Cousins & Jones, 1998; Ockenden *et al.*, 2003). It would appear that the effective management of soils as an active sink for pollutants has potential within the design of the built environment. Consequently, there may be unrealised value in passively managed soil that could add to this sink.

Unsealed soils that have the capacity to support vegetative growth, in particular trees, contribute to bio-filtering of airborne pollutants in the urban environment. PAH and particulate matter collect on leaf surfaces or accumulate within leaves through stomatal uptake (Alfani *et al.*, 2005; Freer-Smith *et al.*, 1997).

Gaseous transfers between soil and air

Globally, soil contains several times as much carbon as the atmosphere and the flux of carbon to soil in plant residues is highly significant in the carbon cycle, being of the order of 60 Pg C per annum (IPCC, 2001). Vegetative matter contributes significantly to soil carbon stocks (Nowack and Crane, 2002) as well as sequestering carbon directly in above ground tissue. Undoubtedly, net carbon sequestration in soil changes as the proportion of land within built environments increases and soil is sealed and modified. The precise impact of these changes at a local level is likely to depend on the specific pattern of land use change. Reduced tillage and higher organic matter additions to soil that is transferred from agriculture to gardens or urban woodland may increase carbon sequestration. Conversely, excavation and mixing of soil during construction may increase microbial utilisation of soil organic carbon leading to a net reduction in sequestration. Little or no information is available to evaluate these and other competing processes. Urban deforestation can decrease the carbon storage capacity of soils (*e.g.* Hagedorn *et al.*, 2001) while carbon sequestration in new urban trees could increase carbon sequestration.

Trace gases are emitted from soil to the atmosphere and some of these are Greenhouse Gases (GHGs). These include methane and nitrous oxide and their release from agricultural soils represent a significant part of overall GHG emissions. There does not appear to be specific information on emissions of GHGs from soil in the built environment although this might be partially assessed by reference to measured emissions from woodland, semi-natural grassland, etc, on the assumption that similar emissions occur for their urban counterparts.

Agricultural soil acts as both a source and sink in relation to atmospheric ammonia. In addition to ammonia derived from inefficient surface application of inorganic nitrogen fertilisers, spreading of slurries and other wastes from intensive livestock and poultry production and food processing can result in ammonia releases from soil (DEFRA, 2002b). Lower emissions might be expected from soil in the built environment than those in all rural areas because of reduced agricultural activity. Nonetheless ammonia releases from soil may occur after land spreading of organic wastes within the built environment and these may be substantial given the output of such materials from wastewater treatment plants, food processing industries, composting plants and even pig and poultry units, all of which are found in the built environment. No systematic study appears to have been made of ammonia releases from soil in the built environment.

Hydrology

The hydrology of urban areas is highly dependent on the proportion of sealed to unsealed soil surfaces. The rate of surface-water runoff for simple sheet flow from a paved surface differs greatly from that in a vegetated system. For instance, using data from Schwab *et al* (1981), the difference in sheet surface flow velocity from a vegetated surface may be 40% slower than that from a concrete surface where there is no infiltration into the soil. Where water does infiltrate into soil and there is no runoff, the rate of water movement in the soil is 10^4 to 10^5 times slower than surface flow velocity from concrete even for the most permeable soil.

Thus unsealed soil represents valuable capacity for storm water management and an important consequence of sealing soil surfaces in the built environment is the increased need to construct storm water drainage to prevent flooding. The need to avoid the high capital costs for hard infrastructure, such as concrete drains and flood defences, has led to the development of Sustainable Urban Drainage Systems (SUDS). In these, soil and vegetation are managed actively to provide water management services. Storm water falling on paved areas that abut green areas can be directed to these soil-based SUDS, altering the flow routes and discharge rates. Soak away systems relying on soil infiltration and runoff infiltration depression areas, connected by vegetated swales, are common features of SUDS.

In addition to increasing rates of surface-water runoff, sealing of soil surfaces reduces aquifer re-charge and available water for trees and amenity planting. This has led to additional concern about soil-surface sealing, including the conversion of gardens to hard surfaces for car parking (*e.g.* Ealing Borough Council (Greater London Authority, 2005)). One response is the use of permeable pavement designs. These are a further important element of SUDS, allowing rapid infiltration to underlying porous

and often soil-based bedding material which is drained to a network of naturally vegetated depressions and ditches.

Water quality

The concentration of housing, wastewater, transport and industry in the built environment, as well as historic contamination, is a hazard to water quality (Goonetilleke *et al.* 2005). Soil is able to intercept contaminants preventing their release to surface and ground waters and in some instances degrading them permanently. The vertical movement of water to ground water is obviously higher where the land surface is not sealed (UI and UM) and soil provides a critical protective barrier to aquifer contamination. Even where the surface is sealed, but sub-soil remains intact (SD) valuable protection may exist. Clearly, where contaminants are trapped in the soil but not degraded (*e.g.* metals), they may accumulate to a level at which the soil is incapable of holding more contaminant or one which compromises the overall soil system and the services it supports.

Abatement of water pollution is a benefit from using SUDS, in addition to hydrological control. This is based on the enhanced retention time for polluted water in soil and vegetation which should allow more effective breakdown of pollutants or their immobilization. Although some studies have demonstrated improved water quality from SUDS systems there is a lack of monitoring data from controlled experiments. Beck (2005) suggests that modelling studies show that real time control of water flows is required to effect quality. Burian *et al.* (2002) have used models to show that nitrate, ammonia and volatile organic carbon levels may be reduced, but this requires corroboration by field measurements. Colin and Melloul (2002) suggest that water resources require protection from pollution even where SUDS are employed. Mitchell (2005) points to a lack of advice on how to target SUDS systems for control of water quality. This may be because, although general principles about pollutant trapping and treatment are well known, the precise processes that operate in say the near anaerobic soil materials beneath a permeable pavement or in swales of infiltration ponds have not been studied in detail.

What is clear is that the efficacy of treatment of water pollutants depends on the soil type, its hydraulic properties and vegetation. In practice, there seems to be limited clear advice available on the role of soil types and their management when considering SUDS systems, although practitioners recognise that soils are ‘important’.

Past activities have led to widespread contamination of soil in the built environment. An important consideration is the potential mobilisation of this contamination in to waters during or as a result of soil disturbance during construction. Designated ‘contaminated’ land will be dealt with under procedures relating to Part II A of the Environmental Protection Act, 1990. Where soil is contaminated with less noxious, albeit environmentally damaging pollutants (*e.g.* phosphates and nitrates), there appears to be no enforceable control within current site construction practice.

Thermal regulation

Urbanisation can have a dramatic effect on the temperature regime of an area through modifications of solar heat exchange and albedo manifested as the urban heat island effect (Levinson and Akabri, 2002; Oke *et al.*, 1981. Vegetation cover in urban areas

(trees, wooded areas, green roofs etc) plays a key control in the atmospheric environment of cities by regulating wind, temperature, precipitation and moisture regimes, particularly in the summer (Avisar, 1996; Hirano *et al.*, 2004; Jonsson, 2004). It is important to note that the cooling effect is driven by having a moist soil so that vegetation can transpire at the potential rate. Retention of soil moisture is facilitated by unsealed conditions and intact profiles that are also able to support vegetation. Green roofs have an important role to play in temperature regulation not only because of evaporative cooling but because the added thermal mass of roof gardens can reduce the amplitude of the temperature variations within the building.

3.1.2 Maintenance (waste processing)

Society imports materials into the built environment, some of which give rise to organic wastes that contain carbon and nutrients that should be recovered. In natural systems, this service is provided by soil organisms. Targets for recycling or composting household waste have been set as part of both the Waste Strategy 2000 (DETR, 2000) and to implement the Landfill directive. By 2010 30% of household waste should be composted or recycled and biodegradable municipal waste in landfill should be 75% of 1995 levels (DEFRA, 2004).

Clearly, organic wastes cannot be spread on soil that has a sealed surface (SD and SS) so the available land area for spreading within the built environment is limited. Additionally, effective processing of waste by soil requires that the soil biology is healthy and this is likely to be compromised by degradation of the soil profile (SM). Thus, capacity for soil-based waste management is confined to land with unsealed soils that have intact profiles (SI) within semi-natural vegetation, gardens, allotments, agriculture, horticulture, parks, sports fields, cemeteries, woodland, water-margins, etc. Optimal use of soil within these land uses for waste management can make a useful contribution to sustainability of the built environment.

Processed organic wastes (such as composted green-wastes) are spread on land used for leisure and recreation (*e.g.* parks and sports fields) and biodiversity conservation. In some cases the recycling loop is completed by municipal authorities that contribute green waste to composting and subsequently utilise the resulting compost in parks, gardens and sports fields (WRAP, 2004). Nearly 70% of biodegradable waste in the UK consists of municipal green waste materials (Riddington and Wise, 2001) and if this is not returned to soil an important supply of carbon substrate for life in built-environment soils is lost. Encouraging composting of green waste and its subsequent use on site would avoid losses of soil organic matter in public areas.

3.2. Food and fibre production

Useful food production requires a significant area of soil that is not sealed and has an intact profile (UI). Within the built environment this exists in domestic gardens and allotments, and where there is land within the “building line” that remains in use for agriculture and horticulture.

There is limited scope for returning land to agriculture and horticulture after it has been used as a platform for buildings and infrastructure, because the soil is too degraded to recover economically. Consequently, the potential capacity available for

food production in the built environment is defined by the current area of land in agriculture, horticulture, allotments, gardens, etc. Historically, this land has assumed strategic importance as during the Second World War when it was extensively converted to food production.

For the future, localised food production should contribute to sustainability goals for the built environment, by reducing food miles and potentially having a positive impact on dietary habits. In addition, valuable educational and recreational resources are provided by existing allotments, gardens and “city farms”. Current food production in the built environment is negligible at a national scale. Commercial agriculture within greater London amounts to 13,566 hectares (MAFF, 1997) with the Lea Valley having the largest area of horticulture (Sustain, 1999) and allotments covering 831 hectares (Sustain, 1999). There are nearly 400 acres of allotments in Leeds and Bradford (Howe and Wheeler, 1999), the majority owned by local authorities. Rough estimates for food production in London amount to 8400 tonnes from commercial sources and 7460 tonnes from allotments (Sustain, 1999). Nationally 13% of gardeners grow fruit and vegetables in their private gardens (Gardening review, 1997) but it is difficult to estimate actual production.

Data is not available on production by commercial farms within the peri-urban built environment. Traditionally, these farms either grew vegetables and salad crops, or produced milk, for sale in nearby urban areas. Although low transport costs from distant producers has removed much of the competitive advantage for local producers, the recent re-emergence of farmers’ markets and other successful initiatives suggests there may be scope for a renewal of peri-urban production. In the long run viability of this depends on continued availability of unsealed soil in good condition (UI).

Urban woodland provides a range of services in addition to fibre production, in particular biodiversity and amenity ones (Woodland Trust). Management of existing woodland and new planting requires soil in an appropriate physical condition. Within parks and other public spaces poor physical conditions impact on tree growth and health (Jim, 1998a). Some previously developed land is returned to woodland, including by natural processes, but its utility for fibre production is limited.

3.3. Habitat and biodiversity

Soil is a below-ground habitat itself and also supports above-ground habitats. The potential capacity for delivery of habitat and biodiversity services is dependent primarily on soil physical properties. These control the soil-water regime for above and below-ground habitats and the “architecture”, as a result of interaction with the biotic components, of the latter. Other factors, including the soil reaction and availability of nutrients are also critical, but second order to the physical properties. If the physical and other “abiotic” conditions are suitable then the soil system can progress through “biotic” barriers to support an optimum biodiversity. Conversely, if soil physical conditions are degraded then the biotic potential is reduced, which is the more common direction within the built environment.

Gardens, parks, transport verges, derelict and other land within the built environment provide valuable habitats. Transfer of agricultural land to the built environment may produce a net increase soil-based habitat support. Within agriculture and forestry, the soil habitat is manipulated to maximise yields of specific species and so the above-

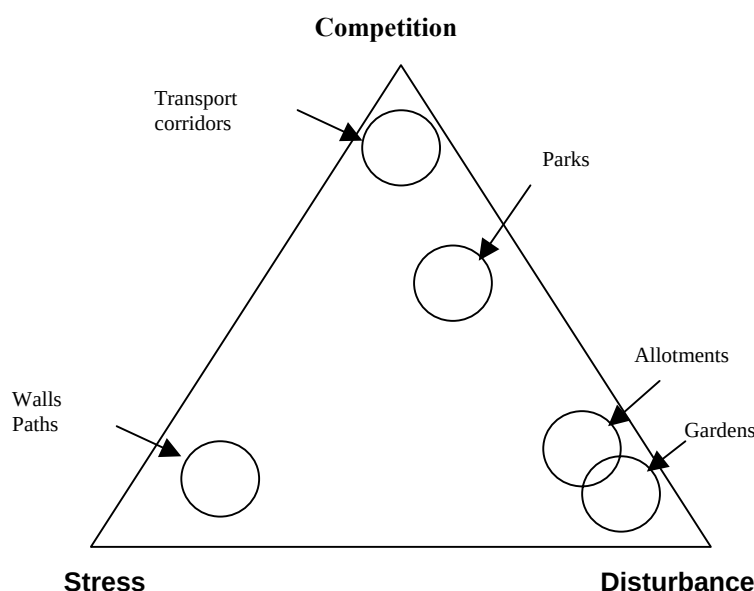
ground biodiversity services provided by soil are reduced. The impact of agriculture and forestry production on delivery of below-ground habitat services is not fully explored. Transfer to the built environment where the soil is not sealed and profiles remain intact could result in a net gain in below-ground biodiversity but this is speculative in the absence of research evidence.

The importance of urban areas for biodiversity has been recognised as being regionally important, both in Europe and globally (Duhme and Pauleit 1998). A key and substantial review of ecology in urban areas has been produced by Pickett and co-workers (2001). Here all aspects of ecology in cities and implications for ecosystem functions are covered, but consideration of soil services is mainly limited to process studies. Although the general ecology of urban areas has been studied, there has been scant attention paid to soil as a habitat. Generally, only those species which have only *part* of their life-cycle in the soil have been considered (*e.g.* McIntyre *et al.*, 2001).

Biodiversity relates as much to quality as quantity. Within the built environment there are a great variety of soil conditions that represent different degrees of adversity for different biological populations. Indeed the overall biodiversity value within the built environment as a whole depends in there being a wide range of different soil-related habitats.

Figure 2 is an adaptation of one developed by Gilbert (1991) in which habitat types in the built environment are mapped in relation to degree of species competition (C), stress (S) and disturbance (D).

Figure 2 Habitat types in the built environment



A broad relationship between the conditions illustrated in Figure 2 and the physical soil conditions can be interpreted. Sealed soils (SI and SD) offer a high stress habitat with poor availability of water and anchorage, compared to those that are unsealed.

Soil that is not sealed and has an intact profile (UI) is most likely to be in a physical condition that will support optimally both below-ground and above-ground biodiversity, in terms of both quality and quantity, particularly where it is managed more intensively to encourage species diversity. However, other soil that is not sealed (UM and some engineered soil) may provide different and valuable habitats that support particular biodiversity. Where the surface is sealed and the profile is degraded (SD), residual soil may still be supporting growth of trees and shrubs, as well as below-ground biodiversity that continues to receive inputs of carbon (via roots) and nutrients (via groundwater). Even where the surface is sealed and the soil profile largely removed by construction of buildings or highways, some remnant below-ground biodiversity may remain, albeit in a relatively dormant or anaerobic condition.

Table 4 attempts to summarise the suitability of different soil types in the built environment for habitat and biodiversity provision, relative to land outside the built environment in semi-natural condition or used for commercial agriculture and forestry.

Table 4 Habitat and biodiversity services

Components	Built Environment				Rural semi-natural land	Agriculture and Forestry
	SD	SS	UM	UI		
<u>Above ground</u>						
Plants	Nil	Low	Good	Good	High	Variable
Fauna	Nil	Low	Good	Good	High	Variable
<u>Below ground</u>						
Mammals etc	Low	Low	Variable	Good	High	Variable
Invertebrates	Low	Low	Variable	Good	High	Variable
Microbes	Low	Low	Variable	Good	High	Variable

In summary, while there is some recognition of the importance of soil in the built environment to sustaining valuable habitats and biodiversity, there are few, if any, examples of studies on urban soils as habitats. As indicated by McIntyre (2000), there is a lack a systematic investigation of soils as habitats that are the basis for life support in urban areas.

3.4. Cultural services

Human beings require a habitat that meets metaphysical and cultural needs as well as physical ones, and soil plays an important role in the latter as well as the former.

The central place of soil in human experience and imagination is reflected in a symbolism which is paradoxical. On the one hand, soil is perceived as a life giving “earth” and on the other as “dirt” and a source of harm. This dichotomy is deep-seated, indeed it has been suggested (Douglas, 1966) that different responses to perceived “dirt” are one of the two dimensions within which all forms of society can be described (the other is a preference for the group or individuals). Here the different cultural roles of soil in the built environment are explored initially in terms of “contribution to well-being” and then this theme is extended to consider the specific

contributions of soil to landscape maintenance and archaeological preservation, which both support an understanding of “place” in space and time.

Contribution to well-being and health

Within the built environment, there is an awareness and experience of soil that is perhaps a continuation of past and much longer human experience when survival depended on an intimate relationship with soil. The smell of soil in gardens and parks after summer showers is especially evocative. Areas of bare soil are valued visual horticultural features that are maintained by careful tillage. Possibly, there are positive feelings aroused by feeling soil. These different stimuli certainly form part of the experience of gardeners and generally enhance the outdoor built environment. Conversely, soil that is poorly managed, compacted, puddled and contaminated is likely to be perceived as “dirty” and detract from a sense of well-being. This contrast can be illustrated by possible responses to soil in areas of bare ground that are converted to “nature” parks. Before conversion, the soil may contribute to a sense of dereliction and even risk of harm, but if this same soil is managed to support trees and shrubs between constructed paths it can become part of a welcoming area for leisure and reflection, contributing to quality of human life as well as biodiversity. There is a sense that soil that is “controlled” contributes to human well-being in the built environment and that this valuable cultural service depends, as do other soil-based services, on active management of soil resources.

Indirect affects of soil on well-being are offered by the service of soil as a platform for vegetation and hence creation of ‘green space’. There is a widely shared public preference for urban scenes that contain vegetation and open spaces to built-up urban scenes (Ulrich, 1986). The biophilia hypothesis proposes that the positive effects of green space are due to an evolutionary human connectivity with nature (Wilson, 1984) and that provision of green space in urban environments satisfies the need for affiliation with nature thereby improving psychological well-being (Gullone, 2000; Ulrich, 1986). Health benefits are also offered indirectly by soil in a variety of green spaces such as park/amenity space (mental and physical; Morris, 2003), allotments (mental and physical; Wiltshire and Azuma, 2000; Wiltshire and Crouch, 2002), and areas of vegetation/trees (improving urban air quality: Freer-Smith *et al.*, 1997). Negative health aspects of urban soils are also apparent from risk of exposure to contaminated soil through direct inhalation/ingestion of soil or ingestion of food produced on contaminated sites (Hough, 2004; DEFRA and the Environment Agency). Conversely, ingestion of non-contaminated soil could have beneficial health effects (Diamond, 1999).

Education

Evidently soils that are sealed and therefore hidden from view cannot provide any direct, useful educational purpose. Unsealed soils provide an opportunity for soil education as an accessible learning resource in school gardens, urban farms, parks and Brownfield sites. Education is both direct, from the perspective of the soil *per se*, and indirect when considering, for example, the environmental sciences, archaeology, engineering or wildlife.

Landscape

“A landscape is a cultural image, a pictorial way of representing, structuring or symbolising surroundings....Indeed the meanings of verbal, visual and built

landscapes have a complex interwoven history” (Cosgrove and Daniels, 1988). Soil contributes to landscape formation and so to its aesthetic. It is both a factor in the formation of particular landscapes and also a component of them. It influences and carries information about the “time-depth” of urban as well as rural landscapes. Soil is one of the elements that create a particular sense of place in different areas of urban as well as rural landscapes (The Landscape Institute and IEMA 2002). Soil is a visual feature. The type of soil present during creation of the built environment may have influenced its character through the types of agriculture, horticulture and associated industries that pre-existed urbanisation. Soil within gardens, parks and verges may support distinctive flora, such as acid-loving shrubs, that are distinctive elements of landscape character. Cultivated soils within allotments create a landscape that is reminiscent of the countryside but accessible within urban boundaries (Crouch & Wiltshire, 2005).

Parks and recreation areas are important elements of the landscapes of most towns and cities. They range from remnants of pre-urban landscapes, such as the Royal Parks of London, to the many parks and public gardens constructed throughout the 18th, 19th and 20th centuries. The value of these to urban quality of life has long been recognised (*e.g.* Beresford, 2003) and this accounts for their survival, even in areas where land values are highest. Private gardens are an equally important element of the built environment, particularly in the suburbs of towns and cities where they occupy a large proportion of the land area. All of these green spaces are supported by soil resources.

Archaeology

Soil is a medium for artefact conservation and may be an artefact itself. Buried natural and human-modified soil and soil-like layers contain information about past habitation, land use and environmental conditions through the preservation of botanical remains and chemical markers (Latalowa *et al.*, 2003; Macphail *et al.*, 2002). Stratigraphy provides essential information about past land-use based on detailed examination of soil profiles. Many important structures such as ancient paths, causeways, field enclosures, fortifications, etc (see Muir 2004) are constructed from soil. Thus soil contains much information about the cultural and physical development of land before and since its transfer in to the built environment.

Soil that is not sealed (UI) may be a valuable reservoir for historical information and archaeology. Surface sealing of soil may protect buried artefacts if the sub-soil profile remains substantially intact (SS) but if the profile is destroyed (SD) or extensively modified (UM) artefacts may be lost. Changes in soil conditions through physical disturbance, biological and chemical alteration as a result of disturbance during site investigation, excavation and construction can impact on the preservation of archaeology. Physical disturbance can result in the loss of information embedded in soil profile development, direct artefact destruction, and soil structural deformation leading to artefact damage. Anaerobic environments aid the preservation of archaeological information, in particular organic material. Disturbance of anaerobic systems through the introduction of oxygen alters the balance of anaerobic conditions resulting in an increase in metal corrosion and microbial oxidation of organic materials. Mitigation strategies are inherently site specific due to the variable nature and spatial extent of archaeological material and soil conditions and the invasive intensity of the intended construction (Williams and Corfield, 2002). The lack of monitoring sub-construction soil conditions after development hinders the assessment

of potential preservation schemes. Several minimal impact methods have been suggested that include the use of non-displacement piles, using previous foundations and limiting invasive excavations (such as basements and underground car parks) to less critical areas of the development area (Williams and Corfield, 2002).

3.5. Platform

Within the built environment there are many components to the platform services provided by soil, reflecting the variety of structures present and their functions (Table 5).

The quality of the platform service provided by a soil is affected by its properties. Depending on these, specific construction techniques and maintenance regimes may be required for built structures. The presence of expansive clay minerals increases the risk of damage to building foundations and buried infrastructure (*e.g.* pipes) caused by shrink-swell cycles as moisture contents change. Some soils which contain naturally higher levels of sulphide or chloride are more corrosive to iron and steel.

Contaminated soil may present possible harm to humans and infrastructure. The risk of harm to humans depends on both the level of contamination and the degree to which retention of contaminants within soil limits their transfer via the food chain, direct physical contact and release to air and water. Contaminated land occurs in the built environment and exists where soil contamination presents a “significant possibility of significant harm” to statutory receptors (DETR, 2000). Where the soil surface is sealed (SS and SD) this may act as barrier to contaminant transfer, unlike for unsealed surfaces (UM and UI).

Table 5 Soil-based Platform services

Land-use	Platform service components				
	Foundations	Supporting surface	Surface water drainage	Thermal modification	Enclosure
Building	*		*	*	
Transport infrastructure (highways, rail, paths, etc)	*	*	*		
Buried infrastructure (pipes, cables, etc)	*				*
Boundaries (walls, fences, etc)	*				
Posts (lighting, signage, etc)	*				
Leisure areas <ul style="list-style-type: none"> - public parks - sports surfaces - private gardens 		*	*		
Cemeteries	*				*

4. Valuation of soil services

4.1. Introduction

Soil is a form of natural capital. Soil-based services may be both private and public goods. In principle, the value of those services that are private, and for which there are markets, could be estimated by reference to financial transactions. For public goods, indirect and often less precise methods of estimation have to be used. In isolation, linkages can be found between individual valuation elements (social, economic or environmental) and a particular soil service, *e.g.* biodiversity services can be valued in terms of environmental value (Pickett, *et al.*, 2001; Bell and Morse, 1999), or, an economic value of soil as a platform for the built environment could be determined based on land value. In other cases, the linkages are more complex and indirect, *e.g.* the social value of environmental regulation services, or the economic value of soil biodiversity. A further difficulty in the valuation of soil-based services is that where they are traded as private goods, *e.g.* platform ones, this is done as part of an overall land transaction, within which soil-based value is only one of many components that determine the total land value.

From the available literature, it is evident that little has been done to value soils from a social, economic and environmental perspective. In an agricultural context, where the soil is actively managed as a resource, the value of soil can be determined directly on the basis of crop yields or livestock yields; or less directly through the contribution of soils to biodiversity, perhaps using the level of Single Farm Payments as one basis for valuation; or indirectly as a part of landscape value and its contribution to tourism income. In the built environment, where much of the soil resource is less actively managed and the stakeholders are not as clearly defined, a suitable valuation procedure has yet to be agreed.

The following section considers two distinct approaches to soil valuation: a holistic valuation, which is made under a 'sustainable development' framework, and then a simple valuation linked to land values.

4.2. Holistic valuation

To provide a complete valuation of soils in the built environment, all soil services would need to be assessed holistically, based on an integration of economic, social and environmental benefits. Holistic valuation of a resource is often determined under a sustainable development framework (Bell and Morse, 1999). The 10-point Bellagio Principles (see below), drawn up in 1996, set out a foundation for monitoring progress towards sustainable development goals which echo those of Agenda 21 (agenda for the 21st century) set by the UN in 1992 (Scott and Gough, 2004).

A summary of the ten Bellagio Principles (modified from Hodge and Hardi (1997) by Bell and Morse (1999)) is as follows:

1. The meaning of sustainable development should be clearly defined
2. Sustainability should be viewed in a holistic sense, including economic, social and environmental components

3. Notions of equity should be included in any perspective of sustainable development. This includes access to resources as well as human rights and other 'non-market' activities that contribute to human and social well-being
4. Time horizon should span both human and ecological time scales, and the spatial scale should include not only local but also long-distance impacts on people and ecosystems
5. Progress towards sustainable development should be based on the measurement of a limited number of indicators based on standardised measurement
6. Methods and data employed for assessment of progress should be open and accessible to all
7. Progress should be effectively communicated to all
8. Broad participation is required
9. Allowance should be made for repeated measurement in order to determine trends and incorporate the results of experience
10. Institutional capacity, in order to monitor progress towards sustainable development, needs to be assured

In the case of soils in the built environment, or indeed soils anywhere, 'human quality of life and biodiversity conservation' provides a clear sustainable development goal. The notion of equity requires inclusion of appropriate access to public and private space, clean soil, air and water, and healthy environments through sustainable environmental regulation, and balanced stakeholder engagement (this is also covered in part by Points 6-8. Under Point 4, proposed urban development plans and modification to soil area use should be made whilst considering the longer term (*e.g.* next 100 years) as well as the forecast demands over the near future (*e.g.* 20 years). This principle also covers spatial scale: from very local (*e.g.* individual houses, gardens and parks, etc.), to local (*e.g.* within the building line), to regional through to national, and trans-national to global.

Progress towards sustainable development should be based on the evaluation of a limited number of indicators based on standardised measurement (Point 5), and would relate to the assessment of resource condition as this affects delivery of identified soil service components. For example, an appropriate set of assessment criteria or metrics might include:

1. A measure of soil sealing (the mapping of buildings and transport infrastructure to determine the area and fragmentation of their footprint; and the permeability of surface materials)
2. A measure of soil profile condition (*i.e.* chemical, physical and hydrological state)
3. The mapping of soil type and intrinsic properties (*e.g.* organic matter content, particle size distribution)
4. A measure of within-soil and soil-supported biodiversity² at targeted sample sites
5. A measure of above-ground biomass quality and quantity (*e.g.* leaf area)
6. A measure of soil pollution loading

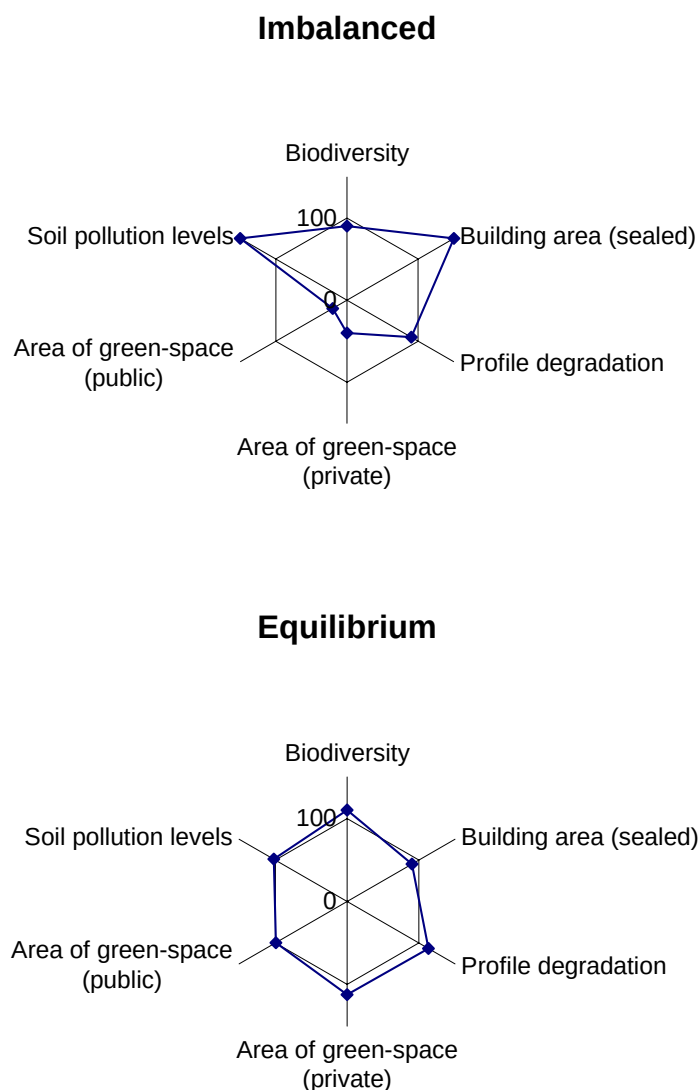
² This could be assessed by straightforward biodiversity measurement (more biodiversity = better ecosystem health); or by indicator species (presence or number of indicator species = better ecosystem health) (Bell and Morse, 1999).

The temporal dimension (Point 9) provides assessment of the rate and direction of change in soil service delivery, in relation to both resource depletion/modification and in the context of current and future environmental pressures (*e.g.* trends through population increases, cultural preferences, climate change, advances in transport and technology).

4.2.1 State indicators

The types of indicators outlined above are ‘state’ indicators, and allow comparisons of condition between geographic locations and over time. Often, state indicators are compared using the AMOEBA model (Ten Brink, *et al.*, 1991) especially over time. It is recognised that to be effective in decision making, the AMOEBA needs to incorporate ‘pressures’ or ‘hazards’ (Bell and Morse, 1999) which are introduced in the risk assessment. A simplified AMOEBA of six indicators in both an ‘imbalanced’ state (undesirable or unsustainable), and an ‘equilibrium’ state (desirable or sustainable) are presented in Figure 3

Figure 3. An illustrative AMOEBA model of sustainability indicators in the built environment.



The benchmark ‘states’ (represented by the 100 % equilibrium line) can only be defined through stakeholder engagement and the value that the stakeholders (including market forces) put on the soil services under consideration. Stakeholder participation in natural resource management not only facilitates complex valuation, but it allows integration and communication between stakeholders leading to shared problem definition (Bouwen and Taillieu, 2004). Valuation is subjective and is a function of the make-up of the stakeholder group, their relative power status, available knowledge and individual and collective understanding of current soil condition, pressures and benefits. The notion of equity (*Bellagio Point 3*) is central if a successful outcome is to be reached. Although a valuation of soil in the built environment using a holistic approach is beyond the scope of this review, this approach is suggested as one basis for progress towards valuation and monitoring.

4.3. Relationship to land values

An alternative approach (and one which could also input to the holistic approach as one valuation component) is to value soil as a function of land value. Whilst this approach does not capture the all-inclusive valuation from stakeholders (public authorities, private business, scientific experts, passive and active users, social interest groups and others), and will not include valuation of hitherto overlooked soil services, it implicitly covers current financial value and provides a way of ranking the value of different soils.

Without development control more or even most land in the built-environment would be used for building, where it is not essential for transport and other infrastructure services. Where land is not used for building or built infrastructure and soil remains unsealed, the development value foregone may provide an estimate of the value of other public good services that have been retained. In particular, where adjacent parcels of land are released for building and retained as green space, the public good value of this green space could be estimated from the foregone value for development. Clearly, this value depends on location because that drives the market value of building land; in the commercial centre of major city, the cost of retaining open space is much greater than it is at the edges of a small town in a region with weak economic performance. This suggests two conclusions. Firstly, the most valuable soil-based service in the built environment is the platform one, which is supported by the tendency for most land to be used for building where this is permitted by development control. Secondly, the value of many soil-based services is location-dependent

It is important to note that some of the components that make up the public good value of land retained as open space in the built environment have no relation to soil. Open space is retained to protect lines of sight to visual features in the landscape; building is sometimes prohibited under flight paths; increasingly, development is being prevented in flood plains; and areas of unsealed land are retained within transport infrastructure to provide boundaries and barriers and embankments; etc. In all these and some other cases soil may be retained passively. However, other land is retained to support services that are soil-derived and which depend on active soil management. These include environmental regulation (*e.g.* SUDS to provide surface water attenuation, ground water re-charge and protection, etc), food production (horticulture, allotments, gardens, etc), biodiversity (nature reserves) and cultural services (sports fields, parks, etc). Where land is retained to provide such soil-based

services, then it may be possible to estimate at least the order of value of these services by reference to the market value of adjacent building land; and then improve on these estimates by estimating the value of, for example, the utility of space for the public good (Woolley and Rose, 2004). This approach suggests that the value of soil in the built environment at a given location can be ranked as follows.

Sealed-soil used for platform services $\geq$ unsealed-soil managed actively in green space $>$ unsealed-soil managed passively.

The implication of this conclusion is that the value of soil-based services being lost by passive management of soil in the built environment may be substantial and could be worth exploiting. Where open land is retained for services that are not soil-based, and as a consequence there is little attention to soil management, untapped natural capital within the soil is not being utilised and in some cases the costs of exploitation may be low in relation to the additional value of soil-based services that could be produced, especially in areas where land values are high.

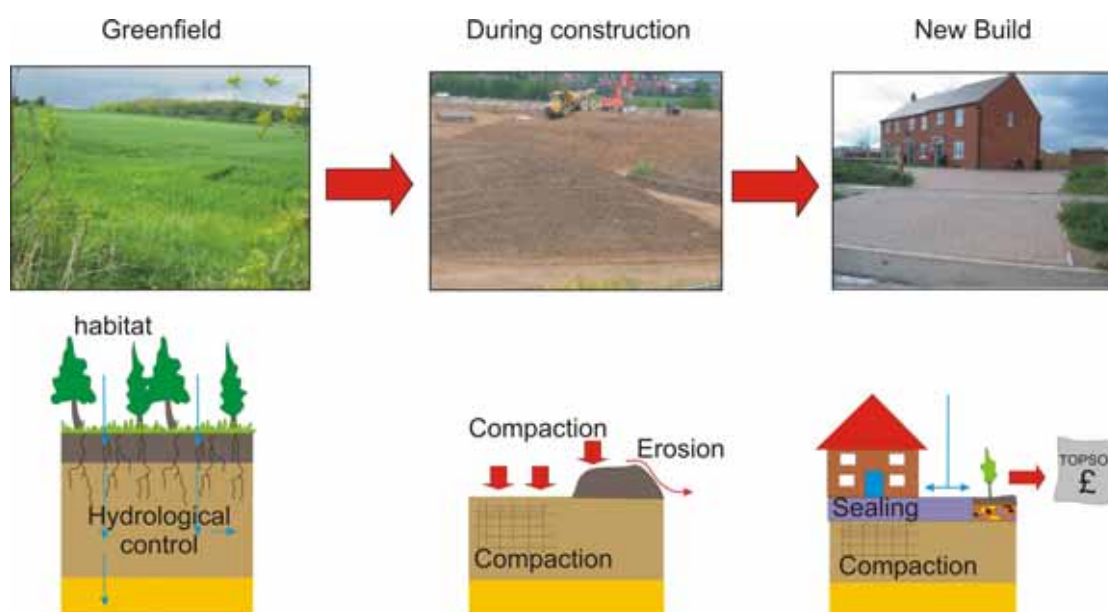
5. Illustrative “story-lines”

A set of storylines have been developed to illustrate and communicate the role of soil in the built environment and some of the threats to its service function.

5.1. Greenfield development

Changes from unsealed intact soil in Greenfield sites to sealed and degraded profiles after development are illustrated in figure 4. The unsealed intact soil profile of the Greenfield site offers extensive environmental services due to connectivity between the soil and the atmosphere. Good soil structure also promotes hydrological regulation and below and above ground habitat. During construction topsoil is stripped and stockpiled on site, which may undergo some degradation if left in this state for a long period of time. Exposed subsoil is severely compacted in preparation for sealed surfaces and stockpiled topsoil is also compacted by site traffic. The resulting profile is severely degraded by compaction and truncation. New development results in a patchwork of soil types, but none that bear any resemblance to the original soil state as a Greenfield site. Surfaces are sealed to provide platform services, resulting in degraded, sealed soils beneath buildings and infrastructure. ‘Green’ unsealed areas within the development may appear to be intact at the surface but will have compacted subsoil, potentially topped with construction rubble and a topsoil cover (often compacted) that has not developed in situ but sourced from stockpiled topsoil across the whole site. The resulting profile although unsealed is degraded and hence compromises certain soil services. Commonly excess topsoil is taken off-site and becomes a commercial commodity to be used and distributed at other development sites or within the built environment.

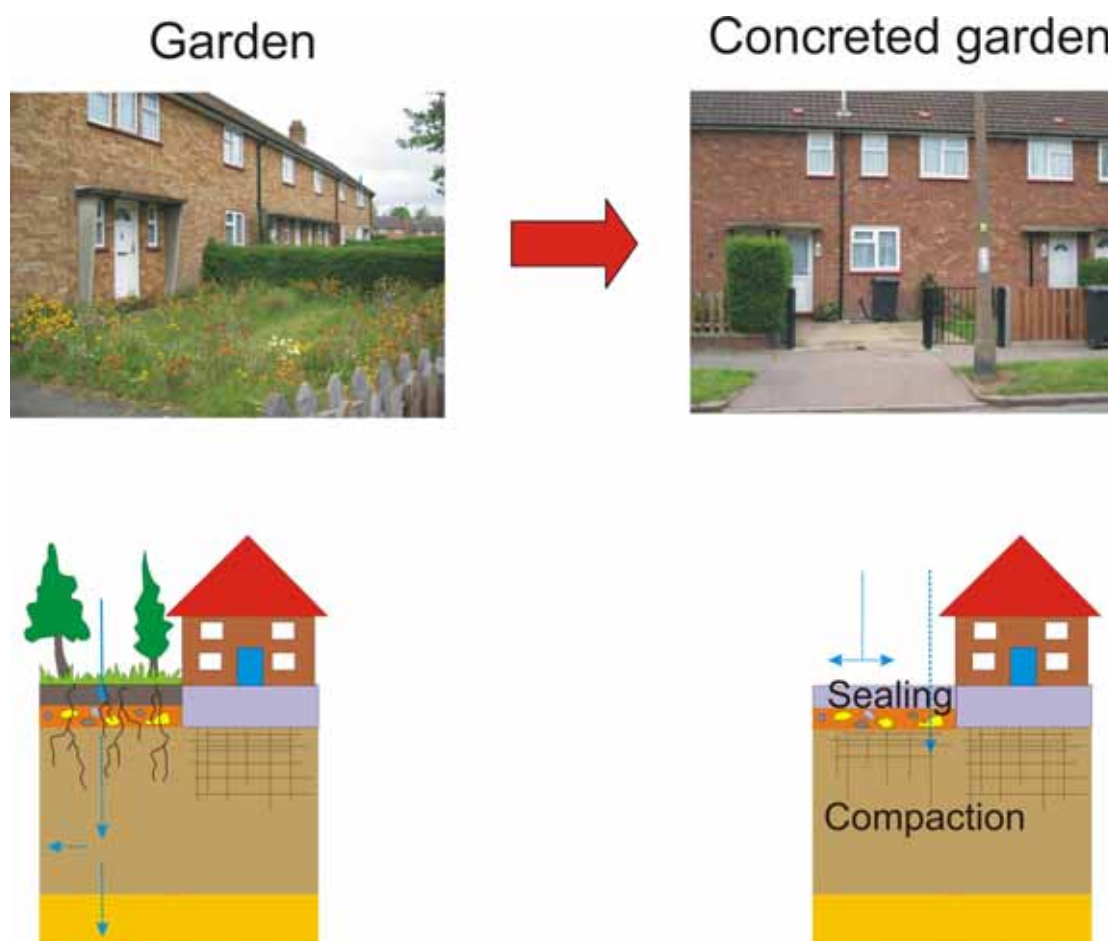
Figure 4 Changes from unsealed intact soil in Greenfield sites to sealed and degraded profiles after building development.



5.2. Sealing Gardens

Conversion of private gardens into driveways and concrete surfaces has become common due to increased car ownership and pressure on public road space (Figure 5). The anthropogenic provenance of garden soils suggests their profiles are probably not originally intact and could contain added material. However, garden soils are unsealed and, depending on their age and amendment history, may have well developed topsoil. The exposure to the atmosphere ensures delivery of many environmental services in addition to providing a habitat (or habitats). Sealing garden soils for driveways would require some ground preparation and hence probable removal of topsoil and introduction of some foundation material. The platform cover can vary from impervious concrete to semi-permeable paving, the former likely to be most common for economic reasons. Ground preparation and subsequent weight bearing from vehicles would cause further profile degradation through compaction. The extent of soil services lost as a result of sealing would be dependent on the permeability of the material used to construct the surface.

Figure 5 Changes from unsealed soil in residential gardens to sealed and degraded profiles after conversion to driveways.

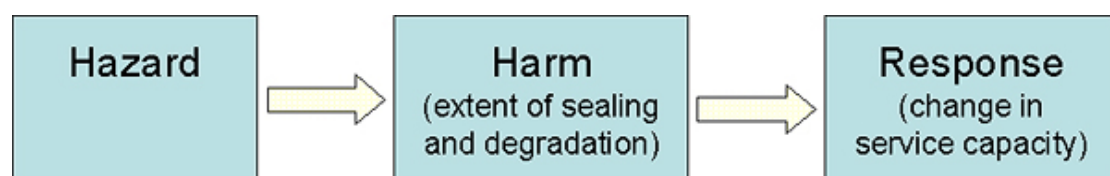


6. Risk assessment of harm to soil in the built environment and impacts of this on soil-based services

6.1. Conceptual model

Figure 6 outlines a general and basic conceptual model for assessing and evaluating risk arising from hazards to soil in the built environment. Hazards are substances, actions or processes that have the potential to cause harm (risk identification). In relation to soil in the built environment we will chose to describe harm as either sealing or profile degradation. The response is the impact of this harm, which may be limited (*e.g.* modification within a service level category) or substantial (*e.g.* when soil transfers from one category to another and a service is curtailed, *e.g.* UI to UM). The likelihood and magnitude of harm arising from a hazard requires assessment (risk assessment). Then, the impact of this harm on service delivery has to be evaluated (risk evaluation).

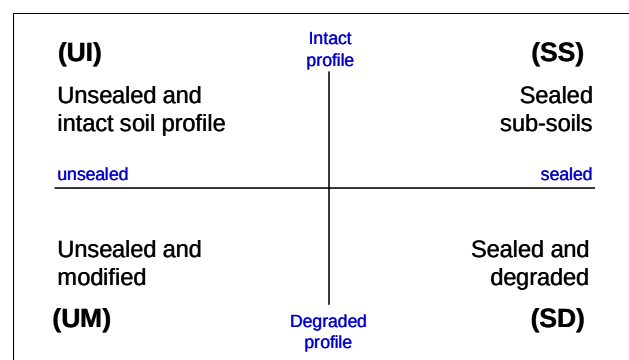
Figure 6. Model for assessing the risk to soil-based services in the built environment.



6.2. Types of harm to soil in the built environment

A typology of soil in the built environment has been proposed (Figure 7) which provides a starting point for describing how different hazards on soil in the built environment may cause harm to soil. Two major kinds of harm were identified, namely surface sealing and profile degradation. The extent of both these kinds of harm is variable, but to simplify their assessment it is appropriate to focus on the four extreme states of soil, which are UI, SS, UM and SD.

Figure 7 Typology for soil in the built environment



As discussed, there are different forms of soil profile degradation (chemical, physical, and hydrological³) and to take account of this the four basic soil states require expansion (*e.g.* UMp = unsealed and modified by physical degradation; UMc = unsealed and modified by chemical contamination; and UMh = unsealed and modified by altered hydrology).

6.3. Types of hazard to soil in the built environment

Examples are listed in table 6 of actual and potential hazards to soils and the harm which they may cause. For each of these, there is an inherent hazard, but much also depends on the operator or developer's competency in managing these situations.

Hazard	Harm	State change
Greenfield development	Sealing, degradation, compaction, possibly replacement, erosion and pollution	UI to SD UI to UMp/UMh/UMc
Ignorance of soil service	Concreting of driveways, sealing	(UI to) UMp to SD ⁴
Increased pressure in public spaces	1) Sealing 2) Surface compaction 3) Erosion	1) UI to SI 2) UI to UMp/UMh 3) UI to UMp
Soil amendments	Increased risk of groundwater pollution by nitrates, loss of seed-bank	UI to UM
Pollution (including diffuse)	Profile damage	UI to UMc
Perception of soil in the urban environment	Sealing, possibly degradation	UI/UM to SD
Climate change	Increased service demand	No immediate change

Table 6 Types of hazard and their potential to harm soil in the built environment

Greenfield development

During site preparation topsoil is commonly removed (stripped) and stockpiled to provide a sub-soil platform for construction. In some cases, the topsoil is transferred to distant sites. Erosion becomes an increased hazard, mitigated only by appropriate soil handling procedures. A further consequence of site preparation is that profiles become degraded and are compacted, eventually being sealed by construction of buildings and infrastructure. Stockpiled topsoil can be mixed with subsoil components

³ Biological modification can occur as a result of importing foreign substances, *e.g.* waste, but a modification in this way cannot be easily equated to degradation. A soil service may be improved by modification. As such it is not included here.

⁴ This implies that the modification from a front garden to a sealed driveway starts from the state of a physically modified profile (UMp), disturbed during building works. The original state before Greenfield development of those areas would have been a UI.

(and other construction materials) and be left exposed for a long time (this could also lead to an increased chance of soil erosion). After construction, topsoil (stockpiled soil) that remains on-site is redistributed and often compacted. Infiltration rates of garden soils are commonly attributed to site history and soil preparation during construction (Hamilton and Waddington, 1999). Any surplus soil is sold and hence taken off-site. Unintentional compaction of areas not intended to be sealed also results from site traffic during construction (Randrup and Dralle, 1997). Tree failure post-construction is common and provides a noticeable above-ground indicator of the loss of soil function as a result of compaction and compromised drainage. The degree to which these occur is dependent on the landscape management advice received, and the competency with which it is implemented on-site.

Soil disturbance during construction increases organic nitrogen mineralization that results in a flush of nitrate to urban groundwater sources (Wakida and Lerner, 2002). Soil sealing severely restricts soil-atmosphere interactions reducing environmental service capacity. Sealing soil surfaces essentially reduces the capacity as a platform for vegetation, limiting the amount of green space in the urban environment. Reduced social value through negative impacts on physical and mental health could be evident as these spaces provide areas for recreation and an enhanced sense of well being through connectivity with nature.

Ignorance of the value of soil services

Paving over front gardens for off-street parking has been identified as a problem in the borough of Ealing. Replacing gardens (unsealed, modified) with hard surfaces for parking (sealed, degraded) has led to concerns about the impacts on biodiversity and aquifer re-charge (Greater London Authority, 2005). Sealing garden soils diminishes environmental services (in particular hydrological aspects) and removes the soil service as a platform for vegetation and biodiversity support.

Increased pressure in public spaces

Greater housing densities and development within the current building line could increase pressure on public amenity areas, leading to soil compaction by increased trampling (*e.g.* Jim, 1998b) that compromises soil services. Construction of paths in open space with inappropriate links between nodes in the built environment leads to the formation of impromptu paths forged by trampling, further degrading unsealed soils.

Soil amendments

Allotments, parks and gardens commonly receive additional nutrient inputs through the use of inorganic nitrogen fertilisers. Although these may be beneficial to plant growth, local soil conditions may be affected significantly and provide a source for diffuse nitrates in the urban environment. Increased loadings may exceed the capacity of soil for buffering and attenuating these pollutants, which could impact on groundwater quality (Lerner, 2003). Pesticides and herbicides applied in urban environments (gardens, parks, railway verges, pavements, amenity and urban agriculture areas) modify unsealed soils and potentially affect urban surface and groundwater quality.

Pollution

In the 1970s and up to the 1990s, there was a concern about lead in the urban environment. Following the removal of lead from gasoline, inputs have fallen. However, many urban soils contain high levels of lead. Other metals and PAH from transport sources are present and persistent in urban soils. Unsealed soils provide a sink for these pollutants, but as a consequence the soil becomes contaminated, potentially compromising the delivery of other soil services. Effective drainage systems should divert contamination away from soil (albeit transferring the problem elsewhere, *i.e.* to watercourses).

Accidental and deliberate waste disposal

Accidental and deliberate disposal of non-organic wastes to land, *e.g.* contaminated water, chemicals, oil, ash, is widespread, although illegal and sometimes leading to prosecution. Small quantities that are regularly added to soil may be as important as single larger disposals. Such additions to soil lead to contamination of soil as well as presenting risks to ground water.

Climate change

Climate change scenarios for the UK highlight increased annual and summer temperatures and lower summer rainfall with a shift to wetter winters and greater frequency of intense precipitation events (Hulme *et al.*, 2002). The pressures of climate change on soil services have not yet been specifically determined (Bradley *et al.*, 2005), whether caused by anthropogenic activity, natural long-term climatic cycles, or both (Pielke, 2004).

Climate change represents a multi-dimensional hazard to soil-based services. Longer term climate change is likely to modify the inherent soil properties and hence service capacity.

More immediately, climate change will affect the soil system itself, by altering especially the water regime and, as a result, alter the inherent capacity of the soil to deliver services. An increased frequency and intensity of precipitation events especially after drier periods could also promote pollutant release from degraded soils and would compromise the capacity of soils to regulate water (Bradley, *loc. cit.*). It will also change the demand for services, both within the wider terrestrial system (*e.g.* via precipitation levels and patterns and also due to changes in societal behaviours).

The appropriate response to climate change is to retain an optimum level of soil-based service capacity, by minimising soil sealing and profile degradation and encouraging active manage and appropriate remedial actions.

6.4. Consequences of harm on capacity for soil-based services

Table 7 provides a summary of the impact of different degrees of soil harm on service levels, with the four basic soil states expanded to accommodate different types of profile degradation (chemical, physical, and hydrological). The sealed-unsealed dimension is simplified by considering SS and SD under one 'sealed' type (denoted as SD in table 1), because analysis shows that these two states support similar capacities for most service components, an exception being archaeological preservation that may be more compromised in a sealed and degraded soil than in a sealed and less degraded

one. Additionally, capacity for habitat and biodiversity services is considered to be only fully present in soil that is neither sealed nor degraded (UI).

An advantage of this approach is that it allows an assessment of the overall impact of the types of harm on service capacity in general. The most valuable soil type (*i.e.* UI) is clearly identifiable, UM soil is valuable but compromised, and SD (and SS) are the least valuable. This general conclusion is useful but is obviously also a simplification. For example, SS only offers two clear services (platform and possibly archaeology) but the platform one may be of greater economic value than other social or environmental services; a third service is one of subsurface lateral water flow. The degree and efficiency of lateral flow is expected to be reduced by construction, depending on both the inherent properties of the soil type (Boorman, *et al*, 1995), and the degree to which the subsurface profile is modified during construction.

Applying relative weightings to the different services to reflect their different values would make the method more robust, but requires a full valuation of all individual service components, which is not available.

Biological modification of soil has not been considered as a harm, as for the most part any such modification will enhance ecosystem service provision. For example, reworking of profiles by earthworms will lead to improved soil structure, water infiltration and storage, and enhanced biodiversity. Similarly, plant roots will stabilise soil surfaces and enhance nutrient cycling and sequester toxins. The major risk of harm comes from the introduction of non-native species of organism. These may replace natives and cause a “passive” harm by inadequately replacing the native species functional role, or “active” harm by destroying native species and impacting significantly on function. An example of this would be New Zealand Flatworms, which prey on native earthworms, resulting in a degradation of soil stability. Urban soils may be particularly prone to this type of degradation due to the large number of sources of non-native materials used in parks and gardens.

Table 7 Summary of effects of soil harm (in relation to soil state) on levels of soil-based services

Service component	Unsealed —————▶ Sealed				
	Intact	Degraded			
	UI	UMc	UMp	UMh	SD
Environmental regulation					
<u>Air</u>					
Sink for airborne pollutants	✓	?	✓x	✓x	x
Carbon sequestration	✓	?	✓x	✓x	x
Trace gas emission	✓	?	?	✓x	x
<u>Surface water</u>					
Pollutant attenuation and degradation	✓	x	?	?	x
Flow attenuation, including flood risk reduction	✓	?	✓x	✓x	x
<u>Groundwater</u>					
Pollutant attenuation and degradation	✓	?	✓x	?	x
Aquifer re-charge control	✓	?	✓x	✓x	x
<u>Thermal</u>	✓	?	✓x	✓x	x
Environmental maintenance					
Waste processing	✓	?	?	?	x
Food and Fibre	✓	✓x	✓x	✓x	x
Cultural					
Well being/health	✓x	✓x	✓x	✓x	✓x
Landscape	✓x	✓x	✓x	✓x	x
Education	✓	✓	✓	✓	x
Archaeology	✓x	✓x	✓x	✓x	x*
Platform	n/a	n/a	n/a	n/a	✓
Habitat and biodiversity					
Primary producers	✓	?	✓x	?	x
Consumers	✓	?	✓x	?	x
Decomposers	✓	?	✓x	?	?

* SS (Fig 7) would be more beneficial to archaeological preservation than SD.

Service levels:

✓	Good
x	Bad
✓x	A range is possible
n/a	n/a
?	Not known

6.5. Review of current practice and possible risk management options and guidance

6.5.1 Introduction

This section identifies possible risk management options and reviews the general efficacy of current practice.

There are several possible generic responses to the outcome of a risk assessment of potential hazards to soil in the built environment, which can be summarised as follows.

1. Refine the risk assessment to evaluate better whether the risk is acceptable or not.
2. Remove the hazard.
3. Attenuate the risk by managing the hazard.
4. Accept the harm.
5. Remediate harm where it occurs.

These options are explored below, in relation to soil sealing and profile degradation.

6.5.2 Sealing

Planning law is the tool used to make risk management decisions about soil sealing, but direct consideration of potential harm to soil is quite limited. A recent report (Sniffer, 2004) stated, “Planning provides a framework for regulating ‘development’, which is defined as comprising the carrying out of building, engineering, mining or other operations in, on or under the land, or the making of any material change in the use of any buildings or other land. It, therefore, is one of the principal means of guiding changes in soil’s function (service) as a platform for development and the way in which other ...(services) may be protected”.

The planning process, including its appeals process, is able to refine risk assessments as part of determinations, but soil is not usually a material consideration, except where a decision has to be made about the need to retain “Best and Most Versatile (BMV) Agricultural Land”.

A range of restrictive planning measures remove the principal hazard leading to soil sealing, which is new construction. These include greenbelt designation, conservation areas and flood plain protection measures. This also includes current government commitments to using land efficiently, and encourages re-development of Brownfield sites. In addition, BMV policy is able to offer some protection from sealing to the higher quality and more versatile agricultural soils.

Both planning law and building regulations have the potential to attenuate soil sealing, by placing restrictions on building density and by requiring soil areas to be retained. At present, where these actions are taken it is for other reasons than soil protection.

A decision to accept soil sealing appears to be a widespread, but the apparent lack of awareness of the value of services that are lost from soil when it is sealed, suggests poor risk management rather than a deliberate management decision.

Under the planning regime, soil restoration requirements can be applied as a condition to planning consents. This is commonplace in relation to mineral extraction and is also applied to major construction projects, but is uncommon generally.

The lack of focus on soil resources in the planning regime reflects the absence of specific policy guidance. This appears to be essential if soil resources are to be afforded the same consideration as for example water, in line with the objectives of the England Soil Action Plan.

Building Regulations offer potential to attenuate the risk of soil sealing during construction by specifying appropriate materials and construction methods. Possible regulations might specify use of porous surfaces for hard-standing or relative proportions of paved and non-paved areas. Currently, there is no deliberate use of building regulations to control the extent of soil sealing in the built environment.

6.5.3 Physical profile degradation

Orientation

The main areas of concern are (1) construction, including of infrastructure as well as buildings (2) management of green space (*e.g.* gardens, parks, and recreation grounds)

Table 8 Types of profile degradation

Degradation type	Description
Truncation	Removal of surface horizons
Burial	Addition of material on profile surface (<i>e.g.</i> imported soil, building rubble, etc)
Admixture	Addition of material by burial, backfilling of excavations etc
Compaction	Compaction at depth within the profile caused by surface pressure from <i>e.g.</i> vehicle traffic , material storage, etc

Construction

Standards and Building Regulations are the tools used to control construction techniques, including ground preparation, addition of materials, vehicle traffic and material storage. The use of these for soil management during construction has recently been reviewed (Sakrabani, *et al*, 2005).

CIRIA (Construction Industry Research and Information Association) and other organisations provide technical guidance, but soil is only considered as an engineering platform to build houses and buildings. There are no guidelines which govern the disposal of the top soils from areas that are being developed. BSI could collaborate with CIRIA to formulate Codes of Practice for sustainable use of soils during planning both at a local, regional and national scale.

Currently there is no requirement for a site soil management plan under the Building Regulations. Where land is contaminated, local authorities assess soil under Part II of the Environment Protection Act 1990, but this is narrow when compared with all the inherent hazards to soils. A proper soil management plan could be a vehicle to refine, on a site-specific basis, the assessment of risk of physical soil profile degradation. Aspects that need to be considered, preferably in a site soil management plan, are the removal of unused imported materials and compaction, and the correct placement of topsoil.

Reducing the use of aggregates and other materials, and restricting the movement of vehicles, offer the possibility to remove a hazard to the physical condition of soil or at least attenuate their impact.

The use of recovered materials to make ground and for essential landscaping may present an increased hazard to soil, although it is desirable from the point of view of sustainable resources management, as it avoids, for example, quarrying of new aggregates and, where materials are recovered on site, can reduce truck movements. The Waste Management Licensing regime defines when the use of recovered materials is acceptable. It does not appear, however, to consider in any serious manner the possible harm to the physical properties of the soil profile that might arise from waste recovery during construction.

Site restoration after construction is normal and essential to remediate an inevitable minimum level of physical damage to soil.

The actual risk of harm to soil on a construction site is affected by the competence of the site operator. If statutory regulations are introduced for site soil management, regulatory effort could be targeted towards poor performers, in a similar manner to that under the Environment Agency's OPRA process.

Green space management

There is no evidence that, for example, local authorities or other major managers of green space in the built environment have soil management plans. Whilst some plans exist to maintain or improve park habitats, no explicit reference to soil is mentioned (except in relation to contamination or a risk of contamination). It is recommended that soil management plans should be prepared by local authorities and other managers of green space in the built environment.

The preparation of a soil management plan allows managers to refine their assessment of risk where this appears to be greater and support a judgement to accept the harm or not.

Compaction is an important type of physical harm which may occur through inappropriate management. Compaction hazards include vehicle movements and pedestrian traffic. An option is to remove these hazards from some areas or attenuate their impact via restricted access. Alternatively, a programme of periodic remediation using air-lifting or sub-soiling may be appropriate.

6.5.4 Chemical contamination

Strong protection against new on-site soil contamination by industrial processes is provided by Pollution Prevention and Control (PPC) Regulations. Licenses to operate the many different industrial processes that fall within PPC place a requirement on operators to make no discharge to soil and a liability for remediation if contamination occurs. An additional requirement under PPC is for operators to assess the possible risk of their operations to the wider environment, including from point source and fugitive emissions.

The waste management licensing regime expressly prohibits the disposal of waste materials on land without an exemption, which can only be granted where there is no possibility of significant environmental harm arising from contaminants. An absolute prohibition on the spreading of Special Waste is an important element of soil protection, but there may be a need for greater consideration of soil contamination *per se*, when assessing applications for exemptions to allow spreading of other wastes.

The Groundwater Regulations prohibit discharge to land of prescribed substances without a permit, but while this may protect soil in some locations where there is a risk of aquifer contamination, it does not in others where the soil and underlying geology are used as a barrier to contaminant transfer.

7. Conclusions

A comprehensive targeted literature review has been conducted. It is concluded that there is limited understanding of soil-based services in the built environment. Economic and social values of soil are less well understood than its environmental value.

Soil has direct and indirect influences on the quality of the urban landscape. Soil that is actively managed contributes more than that which is derelict or only managed passively. These benefits can be realised across the range of soil-based services.

The range of services that soil provides in the built environment is the same as in any other environment, namely, environmental regulation, food and fibre production, waste management, support for habitats as a source of biodiversity, protection of cultural heritage, and platform provision for built infrastructure. It is only the relative mix and direct, or indirect, management to support those services that differs.

In the built environment, interim land-management during construction and subsequent land management, post-development, will affect soil service capacity and delivery in two ways: by sealing of the surface (e.g. buildings and transport infrastructure), and by soil profile modification. Profile modification can range from minor disturbance of remaining green space, to the complete removal of soil horizons, with possible replacement as 'made ground'. Profile degradation also includes physical, chemical or hydrological modification. Sealing can range from partial sealing, through compaction or by being covered with loose material, to complete sealing with impermeable material. Soil sealing has important but only partially explored impacts on hydrology in the built environment. In order to control and manage soil services, the management of these two factors is the key to sustainable management of soil in the built environment.

Intuitively, one might assume that, when greenfield land is developed, there is a reduction in service capacity. When a soil is taken in to the built environment, any loss of food and fibre production might be offset by increased environmental and habitat support services from soil remaining outside building footprints. When brownfield land is re-developed, there could either be a loss or a gain of service capacity, depending on the mix of land uses that are removed compared with those that are introduced.

Whilst it is possible that a change of land use from greenfield to the built environment would result in a net gain in below-ground biodiversity, there is a lack of evidence to support this. The general ecology of urban areas has been studied, but there is insufficient focus on soil itself as a habitat. Soil biodiversity *per se* in urban areas is a little examined topic, requiring focused research effort.

A frame work is needed to optimise the mix and levels of services remaining after land use change. This needs to be underpinned by a broader evidence base of service types and their value. Meanwhile, a lack of knowledge about the detailed range and levels of soil-based services argues for appropriate application of the Precautionary Principle.

The value of soil in the built environment, in relation to carbon sequestration, is unknown, but potentially great. Soil can contain several times as much carbon as the atmosphere and the flux of carbon to soil in plant residues is highly significant in the carbon cycle. Vegetative matter contributes significantly to soil carbon stocks as well as sequestering carbon directly in above ground tissue. Sealing a soil may lock-in carbon within the soil profile to ensure its continuing sequestration, though the majority of organic carbon is likely to have been removed before being sealed. Changes to carbon content, post-construction, can occur through the lateral growth of roots of street trees that grow in tree wells or on adjacent unsealed land.

Undoubtedly, net carbon sequestration in soil changes as the proportion of land within the built environment increases and soil is sealed and modified. The precise impact of these changes at a local level is likely to depend on the specific pattern of land use change. However, there is no information on the net changes in carbon sequestration (to soil) following transfer into the built environment. Similarly, there is a lack of information about green-house gas emission from soil in the built environment.

Flooding, as a consequence of land being modified or built on, is well documented. It is the proportion of sealed to unsealed soil surfaces that largely determines the hydrology of the built environment, where unsealed soil represents valuable capacity for storm water management, and the sealing of soil surfaces reduces aquifer re-charge and available water for trees and amenity planting. Soil and vegetation can be actively managed to provide water management services in the context of Sustainable Urban Drainage Systems (SUDS). Soil based SUDS can be used to direct storm water falling on paved areas that abut green areas, altering the flow routes and discharge rates. Soak away systems relying on soil infiltration and runoff infiltration depression areas, connected by vegetated swales, are common features of SUDS.

In addition to hydrological control, the abatement of water pollution is an additional benefit of using SUDS. Due to enhanced retention time for polluted water in soil and vegetation, SUDS that incorporate soil allow either more effective breakdown of pollutants or their immobilization. The efficacy of treatment of water pollutants depends on the soil type, its hydraulic properties and vegetation. Adversely, SUD systems may lead to an increase in soil contamination.

In practice little clear advice seems to be available on the role of soil types and their management when considering SUDS systems. Furthermore, although general principles about pollutant trapping and treatment are known, the precise processes that operate, for example, beneath a permeable pavement or in swales of infiltration ponds, have not been studied in detail. Consequently, there is a lack of advice on how to target SUDS systems to control water quality.

The evidence base for management of soil in the built environment is greatest in relation to contaminated land and its remediation. However, whilst much is known about the possible risks of soil contamination to human health, surface waters and groundwater, less is known about the effects of contamination on biodiversity, particularly within the soil. Again, these considerations argue strongly for the application of the Precautionary Principle to the control of soil contamination.

The built environment is an important place for buried archaeology. The potential for disturbance of artefacts is significant, both in greenfield and brownfield development. Soil that is intact and unsealed may be a valuable reservoir for historical information and archaeology. Surface sealing of soil may protect buried artefacts if the sub-soil profile remains substantially intact; if the profile is destroyed or extensively modified, artefacts may be lost.

Physical disturbance can result in the loss of information embedded in soil profile development, direct artefact destruction, and soil structural deformation leading to artefact damage. Disturbance of anaerobic systems through the introduction of oxygen alters the balance of anaerobic conditions resulting in an increase in metal corrosion and microbial oxidation of organic materials. A lack of monitoring sub-construction soil conditions, post-development, hinders the assessment of potential preservation schemes. Better understanding and monitoring of soil conditions in the built environment has the potential to enhance archaeological conservation.

The evaluation of soil-based services in the built environment is incomplete. Their environmental value is partially known, but their social value and their direct and indirect economic benefits to society are largely unexplored. The unrealised ecological value of passively managed soil in the built environment (e.g. road-side verges) may be substantial and offer potential for improving sustainability.

In line with the goals of sustainable development, a holistic approach to soil evaluation would seem essential. Preliminary estimates suggest that the total value of the ecosystem services supplied by undisturbed soil may equate with development land values.

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