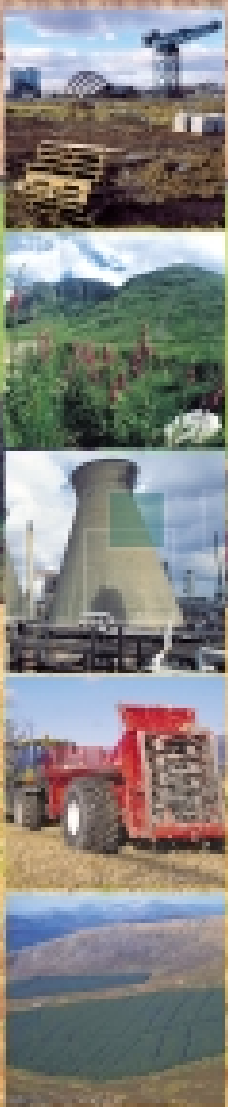
State of the Environment

Soil Quality Report



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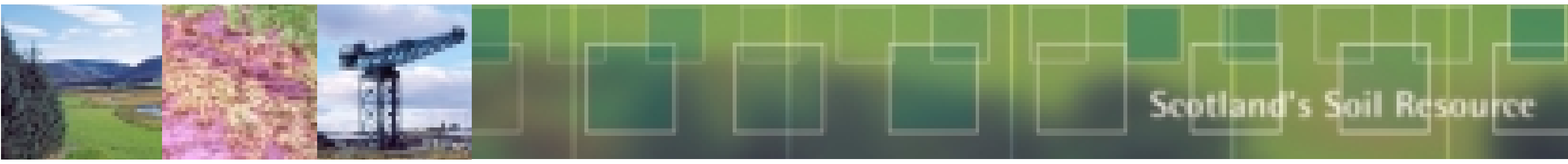

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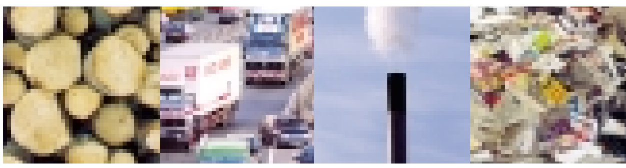

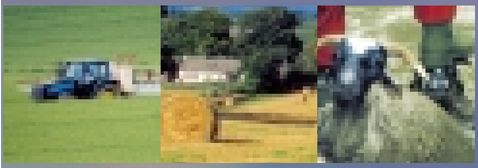

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Foreword

The effects of air and water pollution are visible and obviously threatening to human health but the importance of soil is often overlooked. Perhaps this is understandable because soil's capacity to absorb pollutants has masked their long term effects. Unfortunately, this has meant that much of the legislation and regulation that does mention soil is actually designed to protect our water or air environment rather than soil for its own sake.

But at last this is set to change.

Soil degradation is a global problem. A recent report by the European Environment Agency and the UN Environment Programme concludes there are 150 million hectares of European soils at high risk from erosion and that up to one-third of soils may be significantly degraded. The most serious problems, it suggests, are building works that take soil out of productive use, erosion, slope stability, contamination, acidification, desertification in central and eastern Europe, and large data gaps which hamper decision-making.

The forthcoming Sixth European Environmental Action Plan includes an objective to protect soils from pollution and erosion and proposes a soil protection strategy. It is likely that a Framework Directive will be formulated specifically for soil. All of this provides an international context for SEPA's recommendation for a Scottish soil protection strategy and a framework within which regulation and legislation can be integrated to give our soils the protection they deserve.

Ken Collins
Chairman

Scotland has a large diversity of soil types that react in different ways to environmental pressures. This *State of the Environment Soil Quality Report* sets out to review for the first time the state of our soils. There are few parts of the country that escape the pressures that we inflict on our soil, whether from air pollution, agricultural and forestry practices, including applying waste to land, or from industrial contamination.

There are nearly 12,000 hectares of derelict and vacant land, mostly in and around our towns and cities. Although this area is reducing each year, we do not yet know just how much land has been chemically or radioactively contaminated over the years, or to what degree it is affected. Sulphur and nitrogen deposited from the atmosphere increase the acidity of soil in even the remotest parts of the country. Nearly 80 percent of our land is classed as agricultural. This resource has particular problems arising from fertiliser and pesticide use, erosion and disposal of organic wastes. Agriculture is a large source of the gases that contribute to the greenhouse effect and of ammonia which can contribute to acid rain.

At present, SEPA has limited responsibility for soil. We are recommending here that existing legislation should be integrated, a full assessment of the soil resource should be made and a long-term monitoring strategy should be set up. A soil protection strategy for Scotland should be devised and implemented. SEPA plans to take this forward in partnership with many other organisations and agencies, principally Scottish Natural Heritage.

We are grateful to the many organisations and individual experts who have contributed to or commented on this report. This kind of collaboration has been essential in such a wide ranging subject area.

M Patricia Henton
Chief Executive

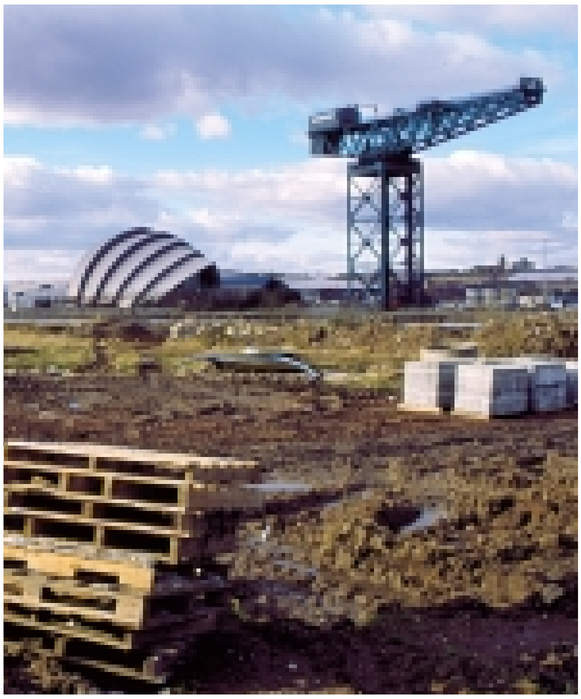
Executive Summary

Scotland's soils are a non-renewable resource. They support the agriculture, forestry and ecosystems upon which humans and wildlife depend and their sustainable use is crucial to maintaining these functions. This report aims to identify the main pressures affecting soils and examine their impact on the quality of soil. In addition, current legislation relevant to soil protection and SEPA's current and future role in soil protection are examined.

The main pressures affecting soils are described in terms of impacts from industry, agriculture and forestry and waste application to land.

Industry

Industry has impacted on soil quality in several ways. There are nearly 12,000 hectares of derelict and vacant land and the full extent of land chemically and radioactively contaminated by industry is not yet known accurately. Deposition of sulphur and nitrogen compounds from the atmosphere affects most land to some extent. The resulting input of acidity exceeds the soil's critical load in over 50% of the land area. If the acidity resulting from ammonia deposition is also included this figure rises to 85%. The most seriously affected areas are in the west-central Highlands, eastern Cairngorms and Dumfries and Galloway. Heavy metals and persistent organic pollutants are also deposited from the atmosphere, although deposition rates and accumulation of these substances in soils are not monitored. Soils will also be affected by climate change. Scotland's climate is expected to become warmer and wetter in the next century.



There are nearly 12,000 hectares of derelict and vacant land

Agriculture and Forestry

Nearly 80% of the land area in Scotland is classified as agricultural and approximately 16% of the land area is forested. Soil erosion has been recorded, both on agricultural land and in the uplands, where the Monadhliath mountains are the most affected. The long-term impacts of inorganic fertiliser and pesticide application on soil are unknown. Inorganic fertiliser application to arable land has averaged 122 kg/ha/y for nitrogen and 49 kg/ha/y for phosphorus in recent years. In addition, 7,767 tonnes (active ingredients) of pesticides were applied to arable land in 1998. Forests have contributed both positively and negatively to soil quality, with impacts depending on management practices. Agriculture is a large source to the atmosphere of greenhouse gases from land-use change, fertiliser use and of ammonia, from intensive livestock rearing.

Waste Application to Land

The application of organic waste, such as sewage sludge, industrial and agricultural wastes, to land can benefit soil quality by adding nutrients and organic matter. However, the waste may contain substances, including heavy metals, organic compounds and pathogens, which are harmful to soil quality and may persist for long periods of time. Over 15 million tonnes of organic waste, mainly agricultural waste, are applied to land annually in Scotland. The amount of sewage sludge applied is expected to rise from 185,000 to 858,000 tonnes by 2005-2006 mainly as a result of additional sewage treatment. The most common types of industrial waste applied to land are distillery waste, blood and gut contents from abattoirs and paper waste. Only the input of heavy metals from sewage sludge application is regulated with limit values. Scotland has 263 licensed landfill sites from which leachate is treated prior to disposal. However, the extent of land contaminated by old landfill sites is unknown.

Impacts on Soil Quality

Negative impacts on soil processes have been recorded for many of the above pressures. Impacts on soil quality can be biological, chemical or physical and may include altered rates of nutrient cycling, altered rates of organic matter decomposition, reduced microbial biodiversity and biomass, loss of organic matter and resultant damage to soil physical structure, and mobilisation of potentially toxic elements, including aluminium. As well as leading to loss of ecosystem functions in the soil, these impacts can have damaging effects on the water and air environments. However, impacts on soil quality are not surveyed or routinely monitored and hence effects on long term sustainability are generally not well understood.

Soil Protection

Soil protection is not specifically addressed by current environmental protection legislation and environmental standards for protecting key soil processes do not exist. There are, however, a number of pieces of legislation relevant to soil quality and SEPA is seeking to incorporate soil protection into its environmental protection activities. SEPA will develop protocols to protect soil quality from emissions by regulated activities and will take into account soil quality when implementing current legislation, particularly when consenting discharges to land and air. Forthcoming legislation has the potential to improve soil quality. However, there is a clear need for soils to be afforded the same level of protection as the water and air environments.

Strathmore farmland from Keillor

Conclusion

The importance of soil as a non-renewable resource essential to a sustainable environment must be recognised. SEPA believes that the principal threats to soil quality and the long-term sustainable use of soils come from agricultural practices, acid deposition and the application of organic wastes to land. However, this report identifies the lack of information about pressures on soils and resulting impacts on soil quality. The lack of data on trends in soil properties makes it impossible to assess whether current land use practices and pollutant inputs to soil are sustainable. For these reasons, SEPA believes a comprehensive monitoring programme is required, to assess the current status of and monitor the quality of soils. SEPA recommends that a soil protection strategy to protect soils from future unsustainable land use practices and pollution should be developed and implemented for Scotland, in partnership with other relevant agencies and organisations.

1. Introduction

Soil supports the natural vegetation, agriculture and forestry upon which people and wildlife depend. Soil also plays an important role in the cycling of elements, such as carbon and nitrogen and in the water cycle through regulating run-off. It also acts as a sink for many contaminants, protecting both the water and air environments from pollution. For these reasons the sustainable management of soil is crucial.

At a global scale it has been estimated that nearly 20 million square kilometres or over 15% of the world's land area has been degraded[1]. The main causes are deforestation, overgrazing and poor agricultural management. In addition, it has been estimated that if degradation of cultivated soils continues at its present rate, reserves of agriculturally usable land may become scarce at a global level by 2015[2]. At a European scale a recent report[3] concluded that Europe's soil resource was being irreversibly lost and degraded at an unprecedented rate. The major problems are soil erosion, slope stability, local and diffuse contamination, soil sealing or loss to development and soil acidification. Soil degradation is expected to continue and probably accelerate if appropriate measures are not taken.

Soil supports natural vegetation, agriculture and forestry
Glen Quaich, Amulree

Scotland's soils are an important and essentially non-renewable resource. The quality of soil has wide ranging effects on many aspects of our environment including agriculture, natural heritage, cultural heritage, landscape, forestry and industry. SEPA has a duty to report on the state of the environment and has previously published reports on Scotland's air and water environments.[4,5] This report examines the wide range of pressures that affect soil quality in Scotland, such as acid deposition, chemical contamination and fertiliser use. They are identified and examined in terms of industry, agriculture and waste disposal to land and their impact is examined in terms of soil processes which contribute to soil quality. For the purposes of this report, soil quality refers to the status of the soil which will sustainably support its multiple functions. For example, supporting an ecosystem, such as moorland, forest or agricultural use while simultaneously acting as a buffer against pollution.

Current legislation relevant to soil protection is also examined. The quality and sustainability of soil have not been specifically addressed by environmental protection legislation, however, there are a number of pieces of legislation pertinent to soil protection. SEPA has a responsibility to protect the environment as a whole from pollution and soil protection is integral to delivery of the Government's goal of sustainable development.

Environmental quality standards do not exist for soil as they do for the water and air environments and therefore there has been no monitoring of pollutant inputs to soil and changing land uses with their resultant impact on soil quality. To date no assessment of the quality and sustainable use of Scotland's soils has been made. This report aims to identify the main pressures and impacts on soil in Scotland with particular reference to SEPA's environmental protection activities. Recommendations are made to ensure the long term protection and sustainable use of soil.

1.1 The Soil Resource

Soil is a complex mixture of weathered minerals, organic matter, organisms, air and water. Soils develop over long timescales and both soil type and rate of formation depend on factors such as geology, climate, vegetation and relief. Soil attributes determine many vital ecosystem functions such as soil fertility and the transformation and degradation of pollutants. Soil organisms, such as bacteria, fungi and earthworms are crucial to the role of biogeochemical cycling of elements such as carbon and nitrogen. It has been estimated that the top 30 cm of one hectare of soil contains an average of 25 tonnes of soil organisms[6].

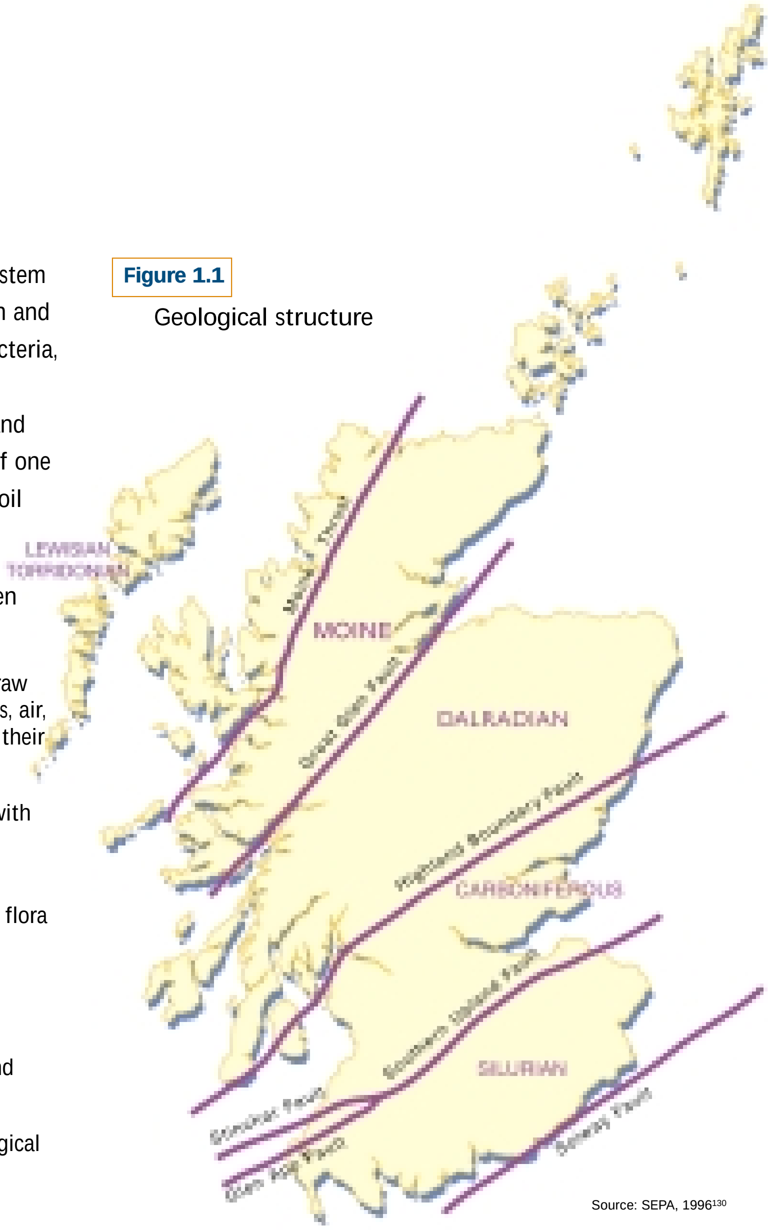
Soils fulfill a wide range of functions which have been defined as[7];

- production of biomass, that is producing food and raw materials while at the same time providing nutrients, air, water and a medium in which plants can penetrate their roots,
- acting as a filter and buffer, enabling soils to deal with harmful substances thus preventing them reaching groundwater or the foodchain,
- acting as a gene reserve and protective medium for flora and fauna,
- providing a spatial base for the erection of human structures,
- providing a source of raw materials such as clays and sands, as well as fuels,
- acting as a source of archaelogical and palaeontological evidence.

Scottish soils are relatively young in geological terms, having begun to develop at the end of the last ice age, around 10,000 to 15,000 years ago. Soils are generally acid, having developed on acidic parent material. The geology of Scotland is complex in detail but has a simple basic structure shown in Figure 1.1. There are three broad provinces and several major faults running from south-west to north-east. Most of the rocks north of the Highland boundary fault are Pre-Cambrian, some date back to over 4,000 million years ago and are among the oldest rocks in the world. Glaciation has removed much of the weathered rock and created steep mountainsides and deep lochs. Intrusions of granitic rocks into the older surrounding rock create particularly high areas of which the Cairngorm plateau is an example. The rocks of the Midland Valley are largely Carboniferous in age, and include coal, oil shales and limestones. Volcanic intrusions have created small areas of hilly land such as the Bathgate Hills and the Campsie Fells. South of the Southern Upland Fault sedimentary rocks of Ordovician and Silurian age produce the high rolling landscapes of the Southern Uplands.

Figure 1.1

Geological structure



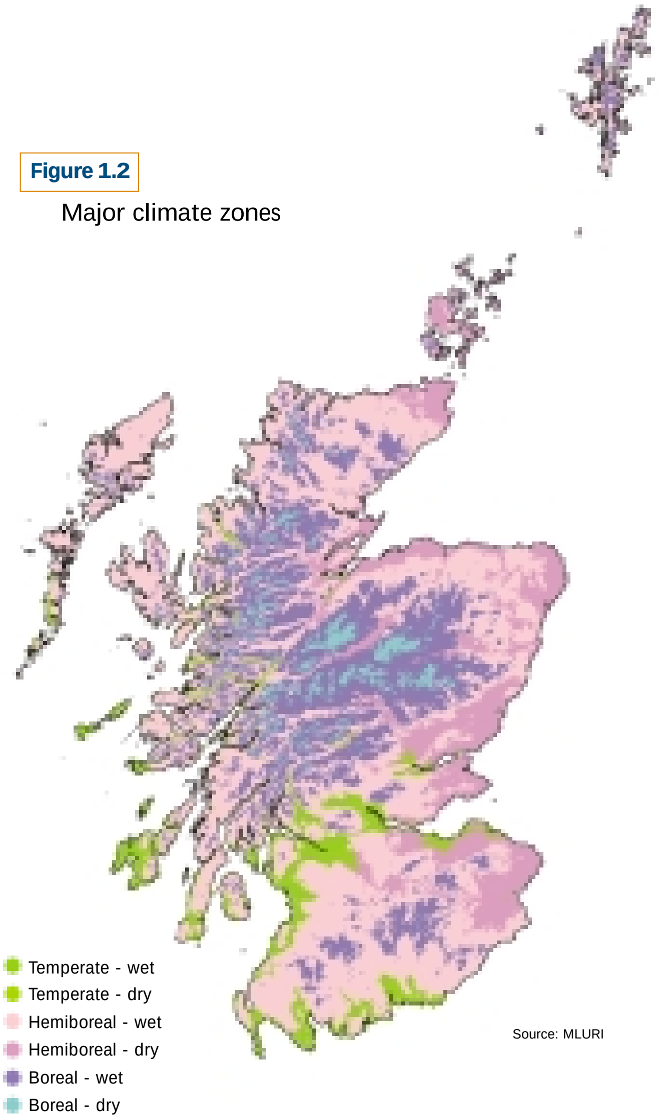
Source: SEPA, 1996[130]

Climate also has a major influence. Due to its position on the western seaboard of Europe, Scotland experiences moderate temperatures for its relatively high latitude. This also results in a moderately wet climate, particularly over high ground along the west coast where annual rainfall can exceed four metres. The major climatic zones of Scotland are shown in Figure 1.2. Geology and climate both strongly influence soils which show a similar distribution to geology and climate, with acidic, waterlogged and peaty soils in the west, and more freely draining and productive soils in the south and east. Agriculture and natural vegetation are in turn influenced by soils and climate and the productivity of the land also determines human population distribution.

The Scottish soil resource contains a number of important soil types including montane soils and peat. Much of this resource supports ecosystems which are sensitive to pollutant impacts and human activities.

Figure 1.2

Major climate zones



The Major Climate Types Classification uses monthly mean values of temperature, rainfall and potential evapotranspiration interpreted from weather stations and is based largely on vegetation requirements for warmth and moisture.

Figure 1.3

Soils of Scotland

The extent of the most common soil types are described below[8] and their location is shown in **Figure 1.3**.

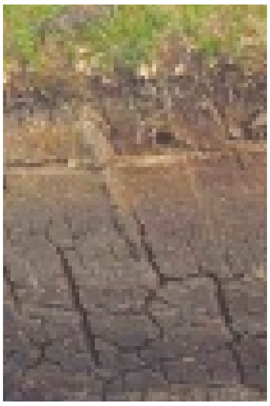
- **Podzols** are the most common soil type occupying 18,480 km² or 24% of the land area. They are characterised by a slowly decomposing acid organic layer overlying a well drained mineral layer from which organic matter and nutrients have been leached to give it a bleached appearance. The organic matter and nutrients may be re-deposited further down the profile.

- **Peats** occupy 16,940 km² or 22% of the land area and are formed by very slow organic matter decomposition due to waterlogging. There are two main types: blanket peat in cool wet climates with vegetation dominated by sphagnum moss; and basin peat in low lying areas where drainage water collects. The resultant slow decomposition rate produces layers of organic matter.

- **Gleys** occupy 10,780 km² or 14% of the land area. Gley soils are created through waterlogging, either through poor drainage or relief. Gley soils are characterised by blue-grey and red mottling colours caused by anaerobic conditions which result in the reduction and oxidation of iron.

- **Brown earths** occupy 9,240 km² or 12% of the land area and are characterised by a fairly deep dark brown horizon rich in organic matter merging into a paler mineral soil as the organic matter content decreases with depth. These soils are generally rich in nutrients and organic matter.

Podzol



Peat

Gley

Brown Earth

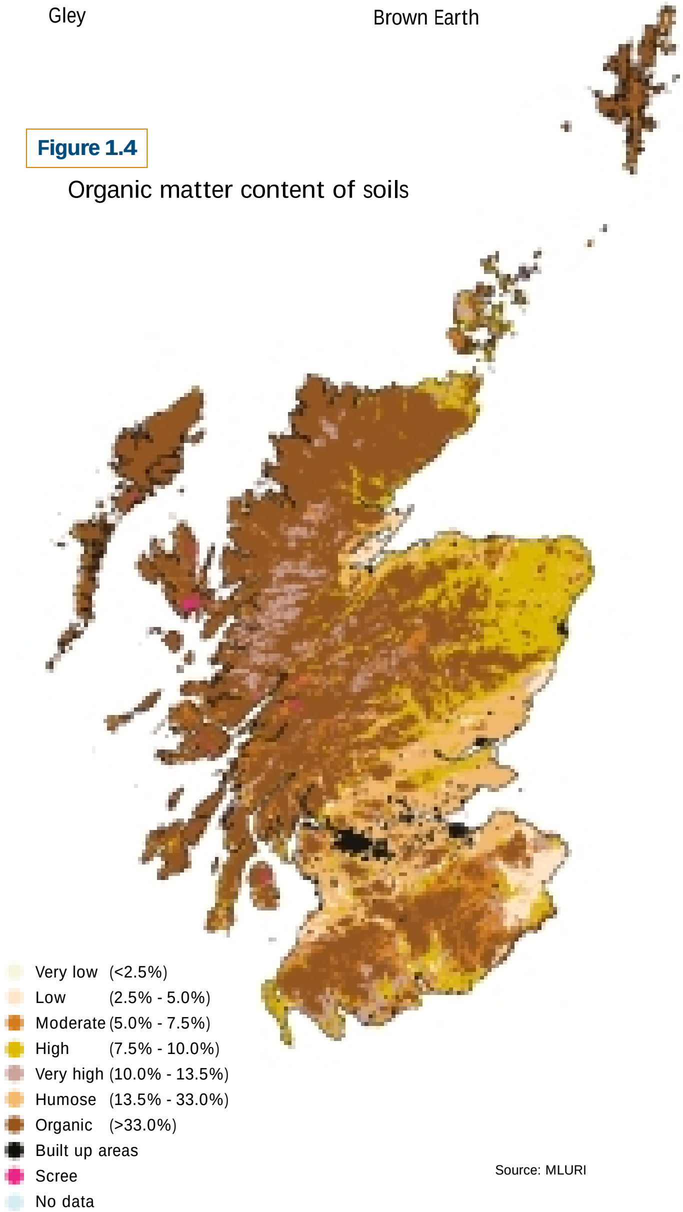
- **Montane soils** occupy 3,850 km² or 5% of the land area. They are generally poorly developed and consist of a shallow organic layer overlying a thin mineral layer under which parent material is found.
- **Lithosols**, **regosols**, **alluvial soils**, **rankers**, **rendzinas**, **calcareous soils**, and **magnesian soils** make up the remaining 4% of the land area.

Figures 1.4 and **1.5** show organic carbon content and pH values in topsoils across Scotland and show the dominance of acidic, organic matter rich soils in the west and more mineral, less acidic soils in the east. When compared with a median organic matter content of 3.4% and median pH value of 6.0 for England and Wales, the median organic matter content 24.3% and median pH 4.4 for Scotland clearly demonstrate the difference in the soil resource[9].

Human activities have modified a large proportion of Scottish soils. In the lowlands, soils have been significantly modified by activities such as forest clearance, grazing, drainage and arable farming. In the uplands, management of sheep and deer, forestry and habitat have all contributed, in varying degrees, to changes in soil characteristics. Diffuse and point source pollution from industry has also contributed to the modification of soil characteristics over much of Scotland (diffuse pollution arises over a wide area, whereas point source comes from a local pollution incident).

Figure 1.4

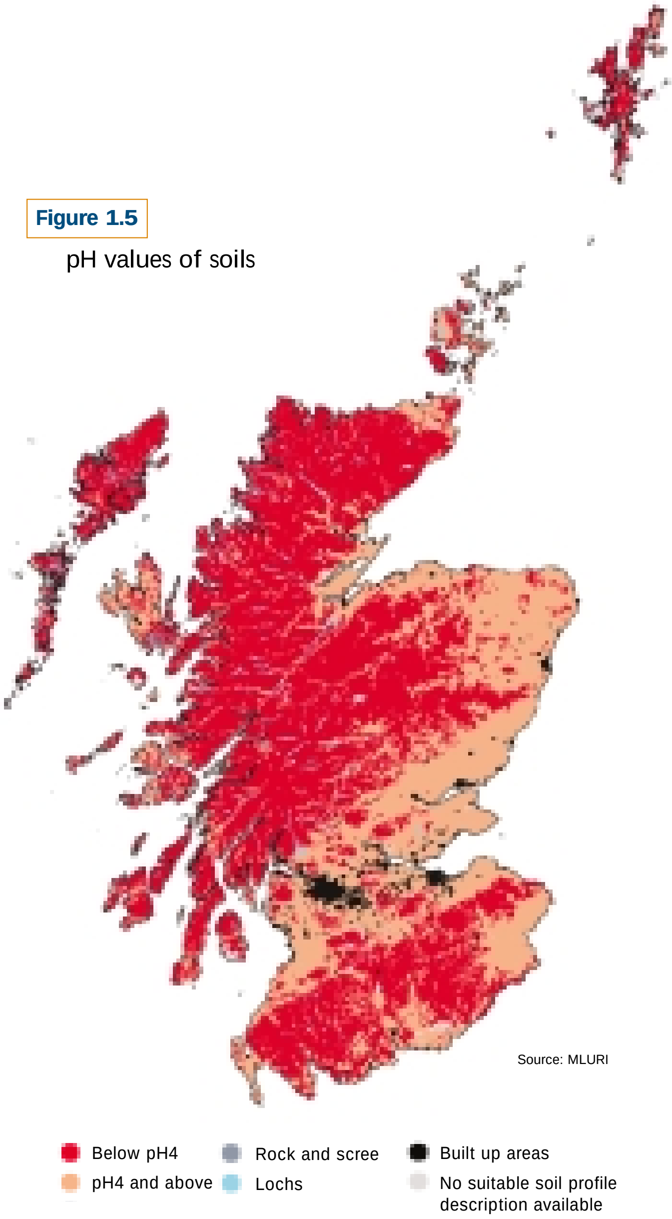
Organic matter content of soils



Source: MLURI

Figure 1.5

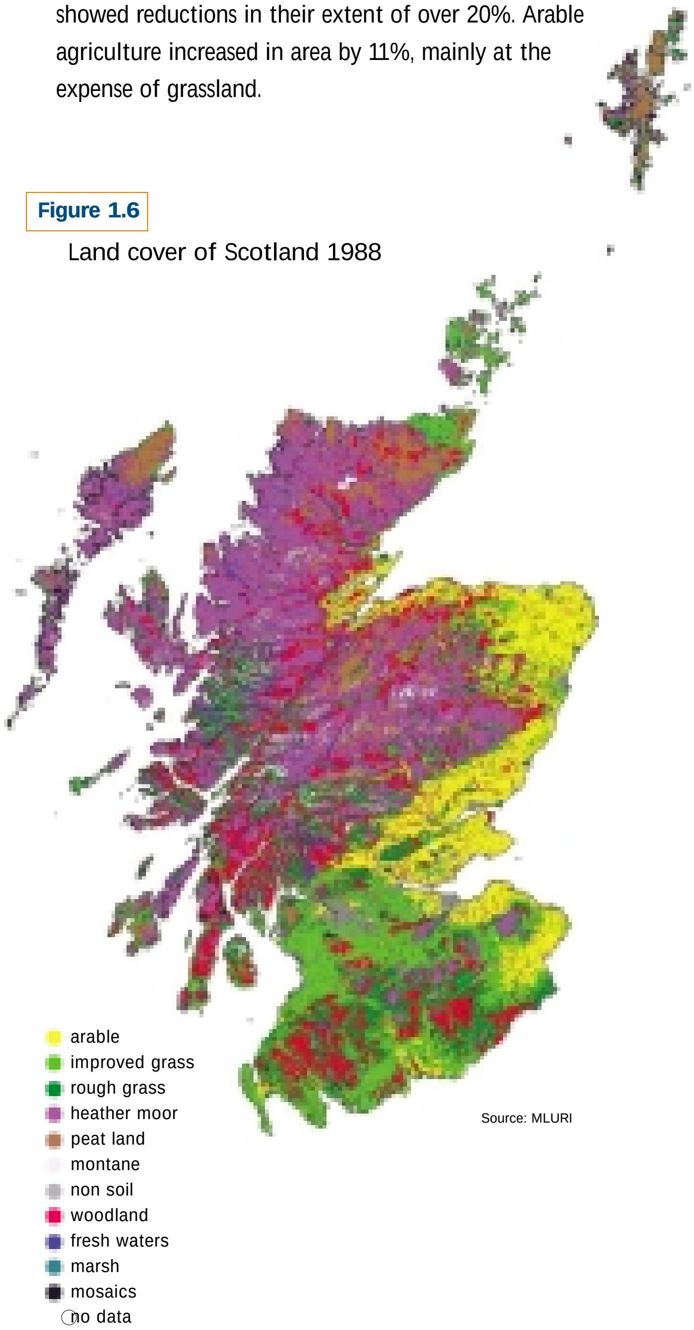
pH values of soils



Land cover has changed significantly in recent years. The National Countryside Monitoring Scheme developed by Scottish Natural Heritage (SNH) estimated land cover change between the 1940s and 1980s[11]. The results are summarised in **Figure 1.7**. The greatest rates of change were observed in the extent of woodland which increased by nearly 200% mainly due to the expansion of conifer plantations. However, areas of broad-leaved and mixed woodland were reduced by 23% and 37% respectively and areas of mire and heather moorland showed reductions in their extent of over 20%. Arable agriculture increased in area by 11%, mainly at the expense of grassland.

Figure 1.6

Land cover of Scotland 1988



The land cover of Scotland is shown in **Figure 1.6**. The percentage area of each cover type is shown in **Table 1.1**. The dominance of arable agriculture along the east coast and of moorland and peatland in the north-west can clearly be seen.

Land use has a strong influence on land cover. Semi-natural vegetation covers over half the country with heather moorland and peatland being the predominant land cover[10]. Arable agriculture and improved grassland cover 11.2% and 13.0% respectively. It should be noted that this is a simplified map of land cover where areas representing plant mosaics have been reclassified according to the dominant vegetation.

Table 1.1

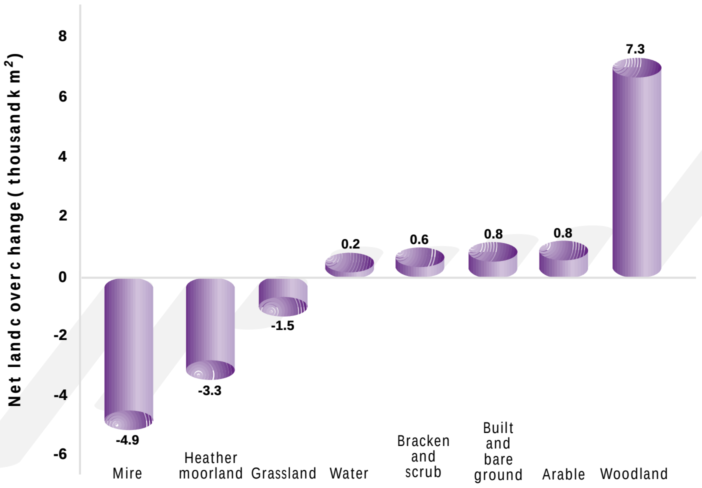
Summary of land cover in 1988

Land cover type	% area
Arable	11.2
Improved grassland	13.0
Rough grassland	15.4
Heather moorland	25.1
Peatland	9.6
Montane	2.0
Non-soil	2.8
Woodland	14.8
Fresh waters	1.9
Marshes	0.3
Remaining mosaics	3.2
No data	0.3

Source: MLURI

Figure 1.7

Net land cover change between the 1940s and 1980s



Source: Mackey et al, 1998[11]

1.2 Soil Quality

There is no universally accepted definition of soil quality. Soil quality is related to physical, chemical and biological properties which allow a soil to sustainably fulfill a specific function, or range of functions, for example, sustaining agricultural production or providing a habitat for semi-natural vegetation while simultaneously acting as a buffer protecting water resources from pollution.

Measuring soil quality is complicated due to the spatial heterogeneity of soil and a lack of understanding of many of the processes, particularly biological, required to sustain a particular function. Indicators representative of soil quality should ideally capture chemical, physical and biological properties that together[12]:

- provide a medium for plant growth and biological activity,
- regulate and partition water flow and storage in the environment, and
- serve as an environmental buffer in the formation and destruction of environmentally hazardous compounds.

Such indicators may include soil pH, water infiltration capacity and microbial biomass. It is also important to develop process-based indicators which provide an indication of the capacity of a soil to perform a particular function[13]. For example it is the bioavailability of a heavy metal, as determined by soil properties, rather than the total concentration which will determine its impact. Parameters which represent good soil quality for arable agriculture, such as nutrient status, will be very different to those for semi-natural vegetation.

Soil type will also have a strong influence on chemical, biological or physical attributes. For example, coniferous forestry occurs across a wide range of soil types in Scotland[14] and rates of, for example, organic matter decomposition are very different on peat as opposed to mineral soil. Despite these difficulties, monitoring indicators of soil quality has been used successfully in other countries, mainly in agricultural systems, to indicate sustainable management techniques[15]. Potential physical, chemical and biological indicators of soil quality are shown in Table 1.2.

Table 1.2

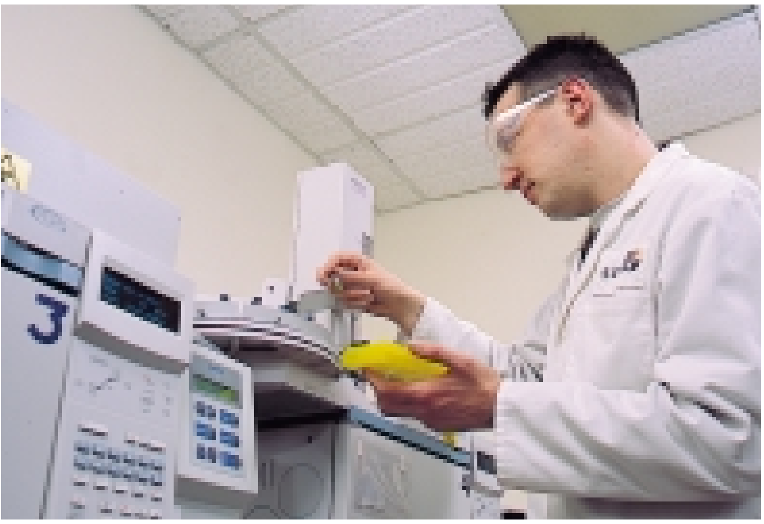
A proposed minimum dataset of physical, chemical and biological indicators for soil quality

Indicator of soil quality	Relationship to soil quality and function	Comparisons for evaluation
Physical		
Texture	Retention and transport of water and chemicals	Less eroded sites or landscape conditions
Depth of topsoil and rooting	Estimate of productivity potential and erosion	Non-cultivated sites or varying landscape positions
Infiltration and soil bulk density	Potential for leaching, productivity and erosion	Row and /or landscape positions
Water holding capacity	Related to water retention, transport and erosion	Precipitation
Chemical		
Soil organic matter	Defines soil fertility, stability and erosion extent	Non-cultivated or native control
pH	Defines biological and chemical activity thresholds	Upper and lower limits for plant and microbial activity
Electrical conductivity	Defines plant and microbial activity thresholds	Upper and lower limits for plant and microbial activity
Extractable nitrogen, phosphorus and potassium	Plant available nutrients and potential for nitrogen loss	Seasonal sufficiency levels for crop growth
Biological		
Microbial biomass carbon and nitrogen	Microbial catalytic potential and repository for carbon and nitrogen	Relative to total carbon and nitrogen or carbon dioxide produced
Potentially mineralisable nitrogen	Soil productivity and nitrogen supplying potential	Relative to total carbon or total nitrogen contents
Soil respiration, water content and temperature	Microbial activity measure	Relative microbial biomass activity, carbon loss versus inputs and total carbon pool

Source: adapted from Doran & Safley, 1997[12]

1.3 Soil Monitoring

There has been limited soil monitoring in Scotland and, with the exception of a few individual sites[16], no long-term monitoring. The soils of Scotland have been mapped at different scales by the Macaulay Land Use Research Institute (MLURI). The National Soils Inventory (NSI) holds information on soil profiles on a five km grid and analytical data, such as pH, organic carbon content and heavy metal concentration on a ten km grid.



Chemistry laboratory for water and soil sampling

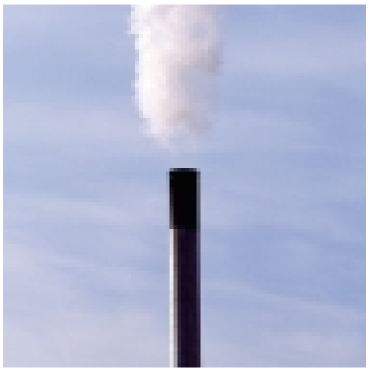
The Countryside Survey 2000, managed by the Natural Environment Research Council's (NERC) Centre for Ecology and Hydrology (CEH), sampled soils for a number of parameters, including heavy metals, organic compounds, pH, faunal diversity and microbiological status, at sites representative of vegetation types across Britain. Results for Scotland will be available in 2001. Soil monitoring is also carried out as part of the multi-agency funded Environmental Change Network. There are three sites in Scotland, Glensaugh in Grampian and Sourhope in the Borders, managed by MLURI and Mharcaid in the Cairngorms managed by CEH. Soil parameters measured include pH, heavy metal concentration, physical properties and soil organisms. Two temporal soil samplings have been carried out to date.

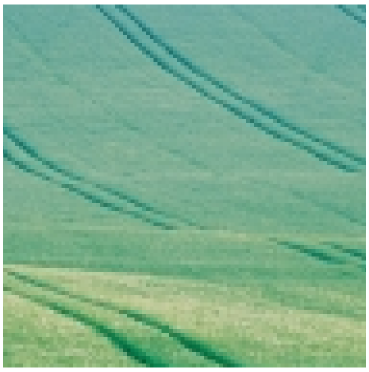
The Scottish Agricultural College's (SAC) Farm Rural Business Division provides an advisory service for farmers, an important part of which is soil fertility testing. SAC routinely measures phosphorus, magnesium, potassium and pH from farms. In addition, forest soil properties are measured at three intensively monitored sites in the United Nations Economic Commission for Europe (UNECE) Level II monitoring programme.

1.4 Pressures on Soil Quality

Many pressures from human activities can affect the physical, biological and chemical components of soil. This report covers the main pressures relevant to SEPA's environmental protection activities, namely industry, agriculture and forestry and waste application to land. It should be noted that impacts from these pressures are not exclusive but are discussed under the principal pressure. For example soil acidification can arise through agricultural practices as well as from deposition of pollutants from industry.

Concern over these pressures is usually focused on their impacts on water and air environments. This report focuses on their impacts on the soil properties and processes which contribute to soil quality. These include effects on biological properties such as nitrification rates, physical properties such as infiltration rates and chemical properties such as changes in pH. The pressures may also impact on soil biodiversity. However, most soil microrganisms are unidentified and the relationship between soil biodiversity and ecosystem function is largely unknown. Research initiatives are now underway to address this[17,18].





- **Impacts of industry** A wide range of potential contaminants are released from industry and may be deposited close to source, as in the case of leaks or spillages, or travel long distances, for example the deposition from the atmosphere of sulphur dioxide. Transport is also responsible for emissions of a number of pollutants. Climate change may have a range of impacts on soils with potential feedback effects increasing greenhouse gas emissions.

- **Impacts of agriculture and forestry** Agriculture and forestry have modified significant areas of land in Scotland. Impacts on soil quality come from fertilisers and pesticides, cultivation practices and overgrazing which may increase the risk of soil loss through erosion. In addition, agricultural soils can be a large source of the greenhouse gases carbon dioxide and nitrous oxide.

- **Impacts of waste application to land** Although wastes can benefit soils through adding organic matter and nutrients, many wastes contain potential contaminants including heavy metals, organic compounds and pathogens which could damage soil quality if not properly managed.

Soil can immobilise many pollutants, effectively acting as a buffer against pollution of water and air. However, this ability is finite, depending on soil properties and processes and must be carefully managed to protect the environment. When conditions which affect this immobilising ability change, for example increasing acidification or changes in land use, the soil can turn into a pollutant source itself, an effect sometimes described as a chemical time bomb. Factors which affect the mobility of pollutants in soil are described in **Chapter 2**.

1.5 Soil Protection Legislation

Soil has not been afforded the same level of protection as the water and air environments. This is partly due to the long timescales over which soils respond to pressures and to difficulties associated with regulating a resource which is primarily in private ownership. In addition, there is no universally accepted definition of soil quality and no numerical standards against which to compare the qualities of different soils in relation to their function, or to monitor changes over time.

Although soil protection is not explicitly covered by legislation, there are a number of regulations which are relevant. Some regulations, such as the Waste Management Licensing Regulations (1994) refer specifically to the protection of soil from pollution. In addition, pollution control in the UK uses the Best Practicable Environmental Option (BPEO) which emphasises protection and conservation of land, air and water.

In 1996, the Royal Commission on Environmental Pollution published its 19th report, entitled *Sustainable Use of Soil*.[19] It made 91 recommendations on various aspects of soil sustainability. The main recommendation to Government was for a Soil Protection Policy for the UK, with the aim of making optimal sustainable use of soil resources.

No single organisation is responsible for all the different aspects of soil protection covered by current legislation. Most land-related issues have been devolved to the Scottish Parliament. The Scottish Executive Rural Affairs Department (SERAD) is mainly responsible for formulating policy and legislation related to land. Local authorities are primarily responsible for land use planning, waste planning and contaminated land. Scottish Natural Heritage (SNH), responsible for nature conservation in Scotland, is the lead agency for soil issues in Britain on behalf of the other conservation agencies. The Forestry Commission in Scotland serves as the the Scottish Executive's Forestry Department. The UK Forestry Standard, which applies to all forestry, whether private or public, has a commitment to the sustainable use of soils. Forest Enterprise (an agency of the Forestry Commission) also manages the 496,000 hectares of publicly owned woodland in Scotland.

Application of sewage sludge to land

SEPA's main aim is:

"To provide an efficient and integrated environmental protection system for Scotland which will both improve the environment and contribute to the Government's goal of sustainable development"

SEPA regulates discharges to prevent pollution of water, land and air, the disposal of waste and the keeping and disposal of radioactive substances. The water, air and soil environments are inextricably linked and all of the pollution prevention and control activities carried out by SEPA potentially impact on soil quality, either directly or indirectly.

The importance of soil protection and the sustainable use of soils has gained recognition in recent years. In producing this report, SEPA's aim is to focus attention and raise awareness of the importance of the protection and sustainable use of soils.

European Community (EC) Directives and UK legislation relevant to (but not specifically designed to address) soil protection.

UK Acts

- Environmental Protection Act 1990
- Town and Country Planning Act (Scotland)1997
- Natural Heritage (Scotland) Act 1991
- Radioactive Substances Act 1993
- Environment Act 1995
- Wildlife and Countryside Act 1981
- Pollution Prevention and Control (Scotland) Act 1999

UK Statutory Instruments

- Protection of Water against Agricultural Nitrate Pollution (Scotland) Regulations 1996
- Sludge (Use in Agriculture) Regulations 1989 (as amended)
- Groundwater Regulations 1998
- Conservation (Natural Habitats) Regulations 1994
- Waste Management Licensing Regulations 1994
- The Conservation (Natural Habitats etc) Regulations 1994
- Control of Major Accident Hazards Regulations 1999
- Environmental Assessment (Scotland) Regulations 1989
- The Environmental Protection (Prescribed Processes and Substances) Regulations 1991
- Urban Waste Water Treatment (Scotland) Regulations 1994
- Pollution Prevention and Control (Scotland) Regulations 2000
- Contaminated Land (Scotland) Regulations (2000)

EC Directives

- Directive on Sewage in Agriculture (86/278/EEC)
- Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora (92/43/EEC)
- The EC Habitats Directive (92/43/EEC)
- Integrated Pollution Prevention and Control Directive (96/61/EC)
- Water Framework Directive (2000/60/EC)
- The Directive on the limitation of emissions of certain pollutants into the air from large combustion plants (88/609/EEC)
- The Directive on air quality standards for nitrogen dioxide ((85/203/EEC)
- The Directive on air quality limit values and guide values for sulphur dioxide and suspended particulates (80/779/EEC)
- The 'Framework' Directive on combating air pollution from industrial plants (84/360/EEC)
- Directive on the Control of Major Accident Hazards (96/82/EC)
- Directive on the Landfilling of Waste (99/31/EC)
- The 'Framework' Directive on Waste (75/442/EEC)
- The Groundwater Directive (80/68/EEC)
- The Nitrates Directive (91/676/EEC)

2. Impacts of Industry

Introduction

SEPA is responsible for regulating a wide range of industrial and manufacturing processes. Under regulations such as Integrated Pollution Control (IPC), Air Pollution Control (APC) and the recently introduced Pollution Prevention and Control (Scotland) Regulations (PPC), limits are set on the emission of prescribed substances, such as sulphur compounds and persistent organic pollutants (POPs), to air, water and land. In addition, the Control of Major Accident Hazard Regulations (COMAH) are designed to limit the environmental consequences of industrial accidents. Regulations are principally designed to protect surface and groundwaters, air quality, ecosystems and human health. Protection of soil quality is not specifically addressed.

Most vacant and derelict land sites are in the central belt

Soil quality can be severely impacted by a wide range of industrial and manufacturing activities. In addition, transport is responsible for a significant proportion of, for example, the precursors of acid deposition and greenhouse gases. The abandonment of land, build-up of toxic chemicals in soil, atmospheric deposition of pollutants and climate change may all have serious implications for soil quality. Pollution can take many forms and can be point source or transboundary. For example, point source pollution such as accumulation of heavy metals in one part of a foundry may lead to pollution of groundwaters or toxic effects on human health, as well as a negative impact on soil quality. Transboundary pollution, such as deposition of acidifying compounds on areas remote from pollutant sources, may lead to soil acidification, leaching of toxic chemicals to surface waters and vegetation change.

In this chapter, the nature and extent of the impacts of industrial activity on soil quality are described in terms of derelict, vacant and contaminated land, atmospheric deposition of acidifying compounds, heavy metals and POPs and the potential impacts of climate change.

2.1 Derelict and Vacant Land

The Issue

Increased awareness of the environmental impacts of development on greenfield land has resulted in renewed interest in re-development of derelict and vacant land, or brownfield sites. Land development means an irreversible loss of the soil resource and plant and animal biodiversity. Brownfield sites are often located in prime development areas although some have value for nature conservation and urban open space making redevelopment undesirable.

State of the Environment

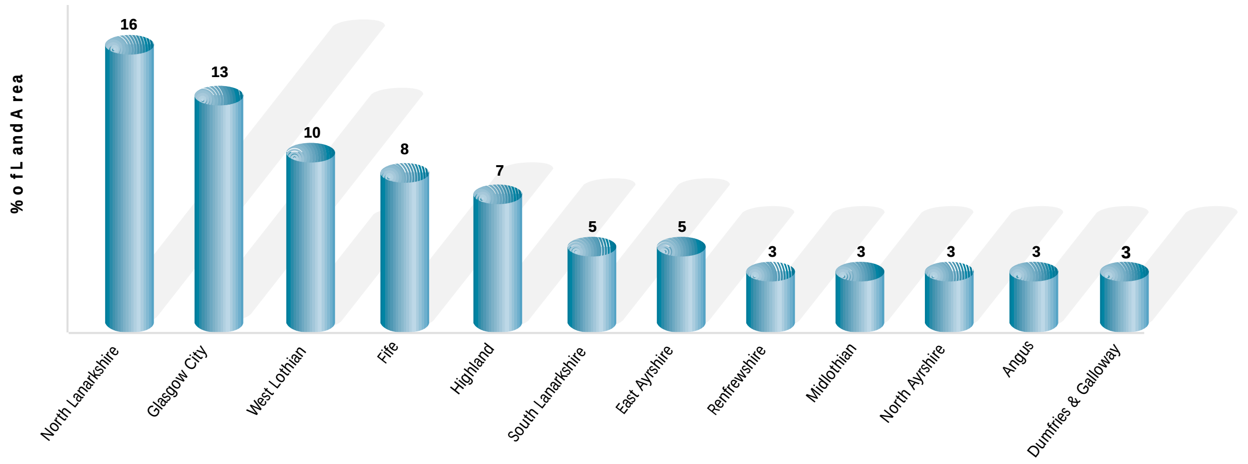
Scotland's industrial activity over the last 200 years has produced an estimated 11,982 hectares, nearly 5,000 individual sites, of vacant and derelict land[20].

Derelict land, as defined by the Scottish Vacant and Derelict Land Survey (SVDLS)[20], is land which has been so damaged by development or use that it is incapable of development for beneficial use without rehabilitation. All sites where contamination is known or suspected are classed as derelict. Typical examples of derelict land include disused mines and mineral workings, abandoned industrial land and disused manufacturing sites.

Vacant land is land in or within one kilometre of the edge of an urban settlement which is unused or unsightly, or land which would benefit from development

Figure 2.1

Derelict and vacant land as a percentage of local authorities' total land area



Source: Scottish Executive, 2000[20]

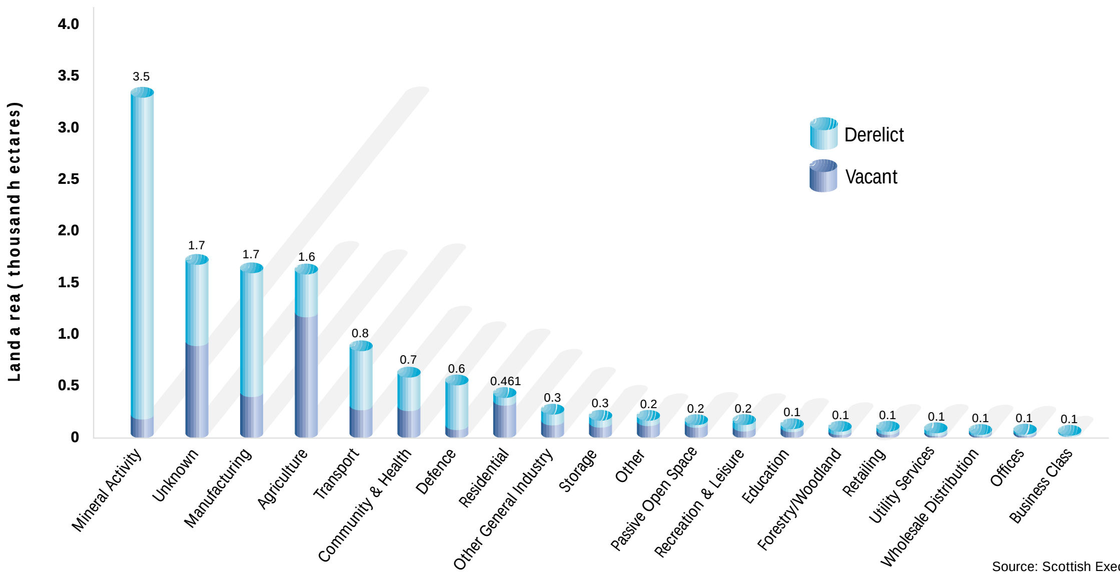
or improvement. Examples of vacant land include land previously used for agriculture and manufacturing. Land classified as vacant or derelict is not necessarily contaminated.

The vast majority of vacant and derelict sites are concentrated in the central belt, with North Lanarkshire (17%), City of Glasgow (13%) and West Lothian (10%) Council areas having the highest proportions. **Figure 2.1** shows the area of vacant and derelict land in the 12 local authorities with the largest extent in 1999. Most vacant and derelict land with known ownership (59%) is in private ownership with 35% being in public ownership. More than half the vacant and derelict land in Scotland has been in that condition for more than fourteen years.

The principal former uses of derelict and vacant land are mineral extraction and agriculture respectively. Manufacturing industry, which includes chemical production, metal works and shipbuilding, is the second most common former use for both vacant and derelict land. **Figure 2.2** shows the previous uses, where known, of vacant and derelict land.

Figure 2.2

Previous uses of vacant and derelict land



Source: Scottish Executive, 2000[20]

Table 2.1

Trend in derelict and vacant land (ha) 1995 to 1999 (SVDLS)[20]

	created	reclaimed	redefined	total
1995	539	824	228	12,721
1996	426	688	380	13,101
1997	610	990	177	12,470
1998	911	823	394	12,209
1998	939	1,429	205	11,982

Although the total extent of vacant and derelict land has decreased in recent years (**Table 2.1**) it is still being created. Of the 1,429 hectares of land reclaimed in 1999, 30% was in West Lothian. Of the derelict land reclaimed the most common new use was for mineral activity followed by residential purposes. For vacant land brought back into use most was for residential purposes, followed by open space and general industry.

In 1996, over 144,000 hectares (0.02%) of Scotland's land area, were developed[10] and on average agricultural land was lost to development at a rate of nearly 1,300 hectares per year between 1991 and 1997. In 1996 there were over 2.1 million households in Scotland and projections suggest a further 210,000 houses will be needed by 2010. It is not known how much of this development will be on greenfield land.

SEPA's role

Loss of greenfield land to development was identified as a priority issue in SEPA's *Environmental Strategy*[21]. However, SEPA does not control the allocation of land for development which is a local authority planning function. SEPA therefore tries to influence local authority development plans to take full account of the costs and benefits of greenfield development. SEPA also responds to planning applications and other consultations encouraging brownfield development, with particular reference to protecting vulnerable ground and surface waters from potential pollution and ensuring compliance with SEPA's natural heritage responsibilities.

Chemicals may contaminate soil

2.2 Chemically Contaminated Land

The Issue

Chemically contaminated land can represent a potential risk to the environment and human health. Typical sources of contamination include mining, metal smelters, oil refineries, gas works, the textile industry and chemical works. Contaminants may be taken up through the soil to plants, animals and through food chains, may be leached to surface and groundwaters, attack building materials or create an explosive hazard. Contaminants encompass a wide range of substances, their impact being dependent not only on their concentration but also on soil properties which affect their mobility and persistence. Soil can act as a buffer to chemical pollution, protecting the water and air environments. Soil properties involved in the mobility of pollutants are described in **Box 2.1**.

State of the Environment

The nature and extent of chemically contaminated land in Scotland is not yet known accurately. The SVDLS[20] estimated that 3,580 hectares, or about one quarter of the total vacant and derelict area, was either suspected or known to be contaminated. The known types of contaminants include arsenic, asbestos, chromium, coal, copper, nickel, zinc, cyanides, gases, phenols and sulphates. Coal was the most common contaminant affecting 588 hectares followed by asbestos on 234 hectares. It is unknown whether 43% of vacant and derelict land is contaminated.

Box 2.1

Soil parameters affecting the fate of pollutants in soil

Pollutants may be immobilised in soil, degraded by soil microorganisms or chemically transformed. Soil effectively acts as a buffer, preventing pollutants entering the water or air environments. The fate of such chemicals is determined by a range of soil parameters outlined below.

Soil pH potentially toxic elements, including heavy metals, become more soluble and hence more mobile with increasing soil acidity. In addition, microbial activity tends to decrease with increasing soil acidity with subsequent impacts on biogeochemical cycling. The optimal pH range is between pH 5 and 8.

Organic matter and clay content the amount of organic matter and clay in a soil determines a soil s ability to adsorb many potential pollutants. The higher the organic matter or clay content the higher the soils adsorption capacity. However, this ability is finite and saturation can occur.

Soil moisture and temperature microbial activity is strongly affected by water content and temperature, which in turn affects the rate at which microbial degredation of potential pollutants occurs.

Redox potential - represents the capacity of a soil for chemical oxidation or reduction processes as determined by microorganism activity and the substances available for reaction in the soil.

In addition, the physical and chemical properties of a pollutant contribute to its environmental fate. For example, hydrophobic pollutants are likely to be immobile due to adsorption onto organic matter.

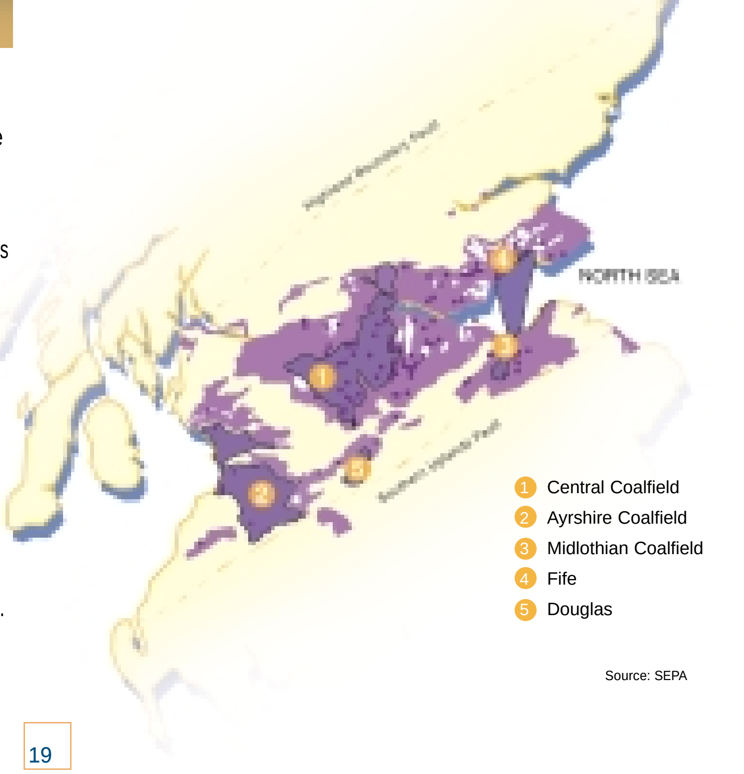
The definition of contaminated land in Part IIA of the Environmental Protection Act 1990, which came into force in July 1999, differs from that used in the SVDLS. The new regulations require significant harm or risk of harm or pollution of controlled waters to be demonstrated, whereas the definition used by SVDLS simply refers to the presence of a number of potential contaminants.

Coal mining has been responsible for a number of pollution issues, most notably water pollution from mine drainage, but also land contamination. The number of deep coal mines decreased from over 200 in the 1950s to only two in 1996. In contrast opencast coal mining has expanded to over 60 opencast operations. **Figure 2.3** shows coalfields and abandoned mines in the central belt. The SVDLS[20] estimated that coal was the most common contaminant. In addition, spoil heaps (bings) are often acidic and may contain high concentrations of heavy metals. Despite pollution problems from leachate, spoil heaps can have a conservation benefit, providing a habitat for rare acid and metal tolerant plants[22].

Elevated levels of potential contaminants are known to occur in urban environments, attributable to a number of sources including industry and transport. A survey of soils in and around Dundee[23] showed above background, and in some cases above maximum permissible, concentrations of a number of metals and organic compounds at sites throughout the city. High concentrations of metals and organics at one site were attributed to contamination following demolition of an incinerator. A similar study in Armadale, West Lothian found a large range in the concentrations of the metals measured. Relatively high concentrations in the vicinity of the town's former steel foundry decreased towards the outskirts of the town[24]. All industrial plants and incinerators are now much more strictly regulated, so dominant continuing sources are mostly diffuse, with transport being particularly significant, but the legacy of former industries will be with us for many decades.

Figure 2.3

The location of coalfields and abandoned mines across the central belt



Source: SEPA

Although there has been no systematic assessment and detailed data on contamination around industrial areas is scarce, several studies have shown negative impacts on aspects of soil quality arising from such contamination. As with impacts of sewage sludge, most studies have focused on the impact of heavy metals, as discussed fully in **section 4.1.1**. Significant reductions in earthworm numbers and biomass have been observed with increasing proximity to a lead, zinc and cadmium smelter[25] and soil contaminated with a range of metals has been shown to be toxic to fungal populations[26]. In addition, metal pollution can affect the functional diversity of soil microbial communities[27]. Oil and diesel contamination has also been shown to adversely affect soil microbial numbers and metabolism[28, 29].

SEPA's role

SEPA has an interest in the remediation of contaminated sites through its existing regulatory controls under water and waste legislation and has been involved with former engineering and manufacturing works, waste disposal sites and fuel processing plants. SEPA either audited the duty of care requirements in the disposal of wastes arising from the sites or issued licenses or consents to control the potential environmental impacts from the disposal or treatment of soil or water. The sites were generally being treated during redevelopment for uses including industry and amenity. For example, as part of a major redevelopment project in response to local economic and environmental concerns and to improve amenity, SEPA issued a waste management license for the stabilisation of mercury contaminated sediments and their disposal to a special landfill site. SEPA also issued waste management licenses for disposal and treatment of tarry wastes generated during redevelopment of a former oil shale plant and detergent works. SEPA controls through consents the discharges from reed beds, one the options for treating contaminated water.

Former Ravenscraig Steelworks in Lanarkshire

A good example of land remediation is Ravenscraig Steelworks which, while in operation, produced a variety of wastes that were disposed of on site. British Steel carried out a remediation programme to make the site suitable for a mixed development of housing, commercial and industrial uses. Excavated waste and contaminated soil were disposed of to a lined landfill site. Leachate from the landfill site is collected and treated in a purpose-built effluent treatment plant.

Contaminant inputs to soil are controlled indirectly by several pieces of legislation including Integrated Pollution Control, Waste Management Licensing Regulations (1999) and the Control of Major Accident Hazard Regulations (1999). These regulations require SEPA to consider the protection of soil when granting licenses. However, there are no standards for the protection of soil quality from regulated substances and concentrations of these substances in soil are not usually monitored. The Pollution Prevention and Control (Scotland) Regulations (2000) cover the risk of harm to the environment as a whole through regulation of industrial processes. This integrated approach includes such aspects as raw material and energy use, waste minimisation and application of cleaner technologies. Importantly for soil quality, the Regulations require that sites are restored to a pre-operational state when activities cease.

Part IIA of the Environmental Protection Act 1990 addresses the problems of historically chemically contaminated land. The definition of contaminated land used in Part IIA is:

"Contaminated land is any land which appears to the local authority in whose area it is situated to be in such a condition, by reason of substances in, on or under the land that -

a) significant harm is being caused or there is a significant possibility of such harm being caused; or

b) pollution of controlled waters is being, or is likely to be caused

"Harm means harm to the health of living organisms or other interference with the ecological systems of which they form part and, in the case of man, includes harm to his property."

Under these new regulations local authorities are responsible for inspecting their areas to identify contaminated land and maintaining a public register of contaminated sites. Remediation of contaminated sites, which can include clean up of soil or placing barriers to prevent chemicals reaching targets such as groundwater, is required. For the majority of sites, local authorities are responsible for ensuring that remediation occurs. However, SEPA is the enforcing authority for contaminated land designated as a special site, which meets one of the descriptions in the regulations, for example, contaminated land on which an IPC process is or has been operated. SEPA is also required to compile a national report on the state of contaminated land.

The definition of contaminated land recognises that concentrations alone do not determine the potential harm from contaminants. Integral to the decision that a contaminant is causing harm is its mobility and availability to humans and other organisms. Potential contaminants may be adsorbed onto soil particles rendering them immobile and unavailable for plant uptake or leaching to watercourses. Soil properties such as pH, organic matter content and redox potential affect the bioavailability of contaminants to receptors. Therefore when site assessment criteria are established, soil conditions affecting bioavailability must be taken into account.

2.3 Radioactively Contaminated Land

The Issue

Radioactive contamination of soil has come mainly from former industrial processes such as luminising using radium, gas mantle manufacture, phosphate manufacture and use, metal ore refining and various other industrial and medical uses of radioisotopes. Other human sources of radioactivity to the land surface include fallout from weapons testing and nuclear accidents, such as Chernobyl. SEPA's responsibilities lie in regulating the controlled disposal of radioactive waste from nuclear sites and other sites such as hospitals, and in monitoring the effects of radioactive discharges to the environment and human food chain.

Contaminated land may pose health risks

State of the Environment

There are several areas of land known to be contaminated by radioactive material in Scotland. Nearly all these sites lie in an area where the land is derelict, has little potential for redevelopment, and the radioactive contaminants are beneath the surface, bound into the soil. Release of contaminants from the soil occurs very slowly and in concentrations which do not pose harm to human health[30]. However, the legacy left by industrial manufacturing of radioactive products and by-products, is such that the nature and total extent of radioactively contaminated land in Scotland is unknown. Regulations are being prepared under Part IIA of the Environment Protection Act 1990 to address this.

SEPA is involved in the remediation of a radioactively contaminated site adjacent to the River Forth in the centre of Stirling. The site once belonged to the Ministry of Defence and was contaminated with radium-226 as a result of luminous paint manufacture. Ways to identify, segregate and dispose of contaminated materials were agreed to make the site suitable for other uses.

SEPA independently monitors all licensed nuclear sites in Scotland. The results from this programme are published annually in the *Radioactivity in Food and the Environment Report*[31]. A large proportion of the monitoring is focused on the marine environment into which the nuclear installations discharge most of their emissions. Historically, soil samples have only been analysed around the Dounreay research facility in Caithness. However, since April 2000, soil samples are monitored around all of the licensed nuclear sites.

SEPA is responsible for licensing low level radioactive waste disposal to landfill, such as waste from hospitals and research institutions where such material is used in patient care and scientific research. In Scotland 12 landfill sites are licensed for radioactive waste disposal, in accordance with a SEPA authorisation instructing site operators to take special precautions during disposal. As a minimum, these precautions include bagging the waste and burying it beneath at least 1.5 m of inert material. Leachate in and around the 12 sites is monitored. This sampling reports levels of radioactivity well below the annual dose limit to members of the public of 1mSv (millisievert) from all artificial sources. Tritium was found in leachate from some landfill sites, but the radiological significance of the levels was considered negligible.

Fallout from the Chernobyl nuclear accident was one of the most widespread sources of radioactivity to land. The Institute of Terrestrial Ecology surveyed the resultant radioactive contamination in 1987 and found high deposition in upland areas of Scotland, with the highest rates in the central Highlands, the southern area of the former Central Region and Galloway. Caesium-137 is more available for plant uptake on organic soils commonly found in upland areas compared to mineral lowland soils[32]. Following the Chernobyl accident, vegetation growing on such organic upland soils had transfer rates from soil to plant that were far greater than on lowland soils. In 1986 restrictions on the movement and slaughter of sheep were placed on over 2,000 farms. In 1999 only 20 farms in East Ayrshire, East Renfrewshire and Stirlingshire remained under control. Recent observations have shown a decline in levels of caesium-137 in soils, thought to be linked to the fixing of the caesium ions within the soil[33].

There have been many models developed since the Chernobyl accident to predict which environments would be vulnerable following a nuclear accident. The SAVE (Spatial Analysis of Vulnerable Ecosystems) model identified organic soils, such as those commonly found in western Scotland, as being potentially the most vulnerable should such an incident occur again[34].

SEPA's role

SEPA is primarily concerned with regulating radioactive waste disposal from nuclear sites, hospitals, research premises and industrial sites. Under Part IIA of the Environment Protection Act 1990 new regulations for the control and remediation of radioactively contaminated land are planned and the provisions may come into force in 2001. The regulations, similar to those for chemically contaminated land, are likely to place responsibility jointly with SEPA and the Local Authorities to survey and report on the nature, extent and risks associated with radioactively contaminated land in Scotland. Where intervention is warranted, based on the results of a risk assessment, SEPA will be responsible for supervising the remediation of the radioactively contaminated land.

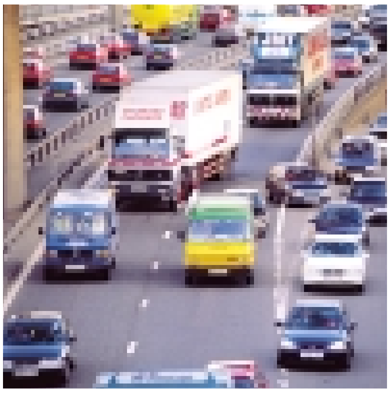
High rainfall in upland areas can increase acidification

2.4 Deposition from the Atmosphere

A wide range of compounds are emitted to the atmosphere from industry and transport. Their deposition to the land surface can have a range of impacts on soil quality including soil acidification and eutrophication, changes to the rates of biogeochemical cycling and loss of ecosystem function. In turn, these effects can have a negative impact on the air and water environments, on biodiversity and on human health. For example, soil acidification and eutrophication can lead directly to the leaching of nitrate and aluminium to surface waters, the emission of the greenhouse gas nitrous oxide to the atmosphere, and changes in the species distribution and biodiversity of vegetation in sensitive ecosystems.

The principal source of ammonia is agriculture. These compounds can be deposited from the atmosphere by several mechanisms; by wet, dry or cloud deposition. Pollutants vary widely in the distance they travel before deposition. For example, sulphur compounds may travel thousands of kilometres before being deposited in areas remote from sources, whereas ammonia tends to have a much shorter residence time in the atmosphere and is deposited relatively close to its source.

Current legislation to reduce acidification is based on the critical loads approach. The definition of critical loads used by the United Nations Economic Commission for Europe (UNECE) is:



2.4.1 Acidifying and Eutrophying Compounds

The Issue

The term acid rain, first used in the 19th century, describes the atmospheric deposition of sulphuric and nitric acids to the land surface. Acid deposition has been shown to have serious impacts on the health of soil, vegetation and freshwater ecosystems throughout Europe. The principal precursors of acid rain are the oxides of sulphur and nitrogen which can form sulphuric and nitric acid in the atmosphere. Ammonia, although alkaline, can produce acidity following chemical transformations in the soil. The main source of oxides of sulphur and nitrogen is burning fossil fuels in large combustion plants and motor vehicles.

"a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on sensitive elements of the environment do not occur according to present knowledge".

Critical loads for sulphur and nitrogen and other pollutants can be calculated for soils, freshwaters and vegetation[35] then compared with the input of that pollutant. Maps can then be produced to show where pollutant inputs exceed critical loads and where environmental damage is likely to occur. For soils, critical loads have been calculated using soil mineralogy and chemistry to indicate buffering capacity or sensitivity to acidification[35]. A separate methodology has been developed for peat soils based on the relationship between the acidity of rainfall and the acidity of peat[36].

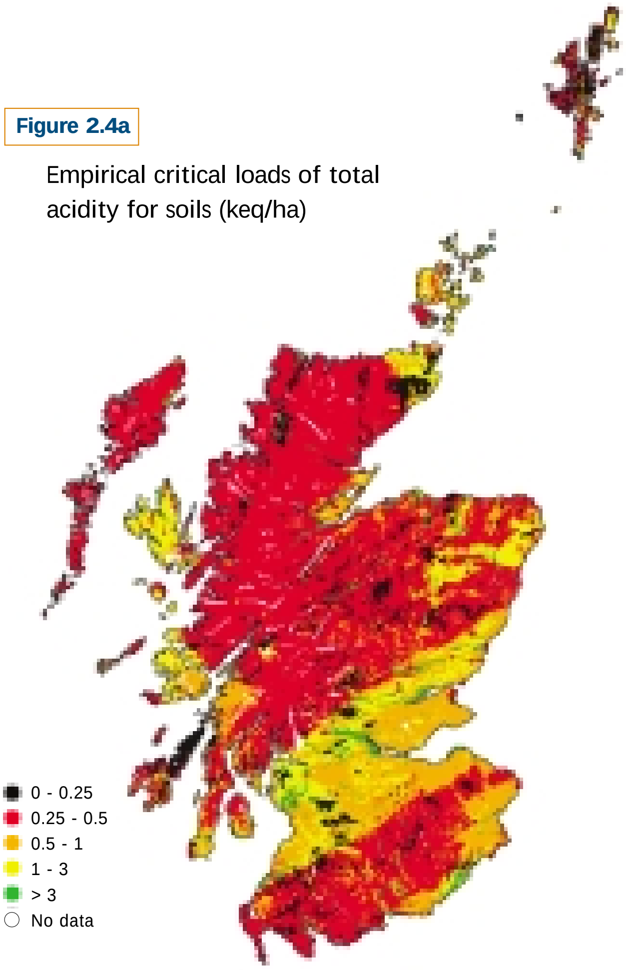
State of the Environment

The transboundary nature of acid deposition has resulted in concerted action across Europe to reduce emissions of sulphur and nitrogen compounds. Emissions of sulphur dioxide from Europe have decreased by over 50% between 1980 and 1995[37] as a result of EC Directives designed to mitigate emissions from industry. Between 1979 and 1993 sulphur deposition to soils in the UK declined by up to 70%[38]. Partly as a consequence, some farmers in north east Scotland now need to apply sulphur as a fertiliser because of the low levels in soils.

Rates of sulphur deposition in Scotland ranged from less than 6 to over 20 kg S/ha/y in 1995 with the majority of sites receiving between 6 and 12 kg S/ha/y[39]. The transboundary nature of air pollution is demonstrated by the import and export of sulphur compounds to and from Scotland. It has been estimated[39] that 80% of the sulphur deposited comes from outside Scotland (33% from England and Wales, 4% from Northern Ireland and 44% from the rest of Europe) and 80% of sulphur emitted in Scotland is exported.

Figure 2.4a

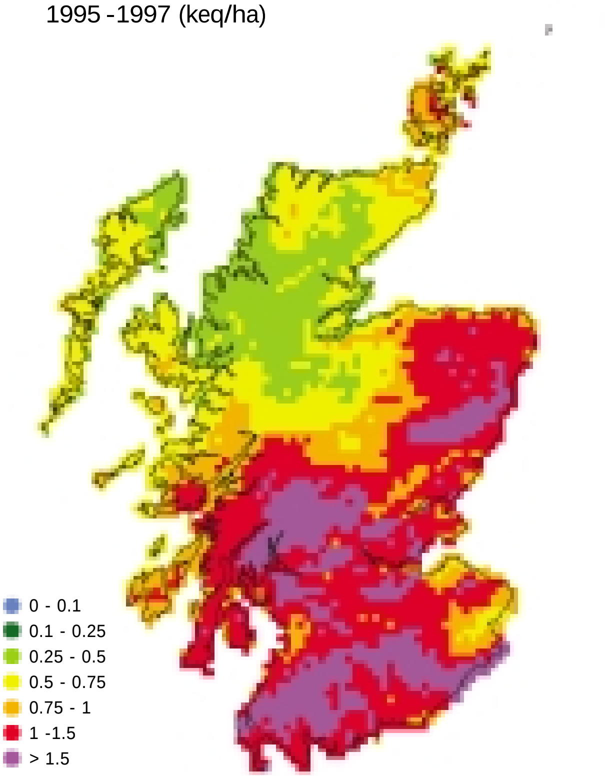
Empirical critical loads of total acidity for soils (keq/ha)



Source: MLURI, Aberdeen University, CEH

Figure 2.4b

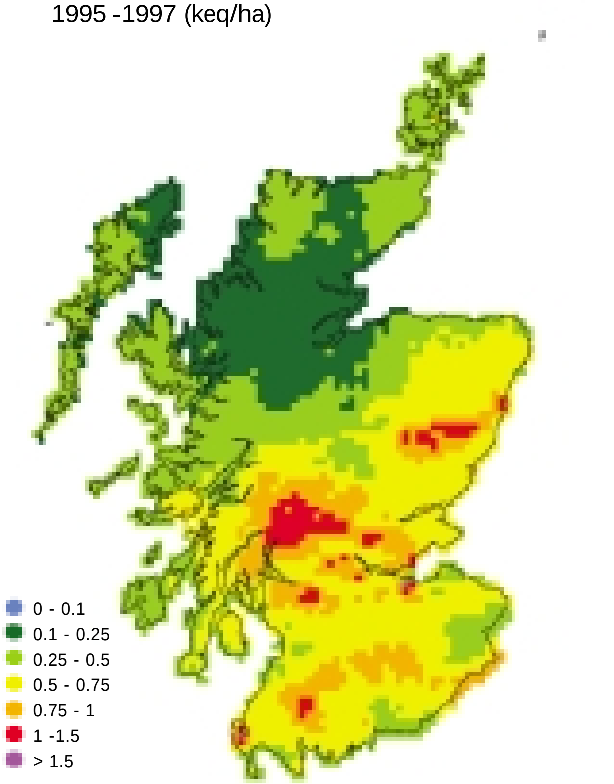
Total acid deposition including NH_3 1995 - 1997 (keq/ha)



Source: CEH, MLURI, Aberdeen University

Figure 2.4c

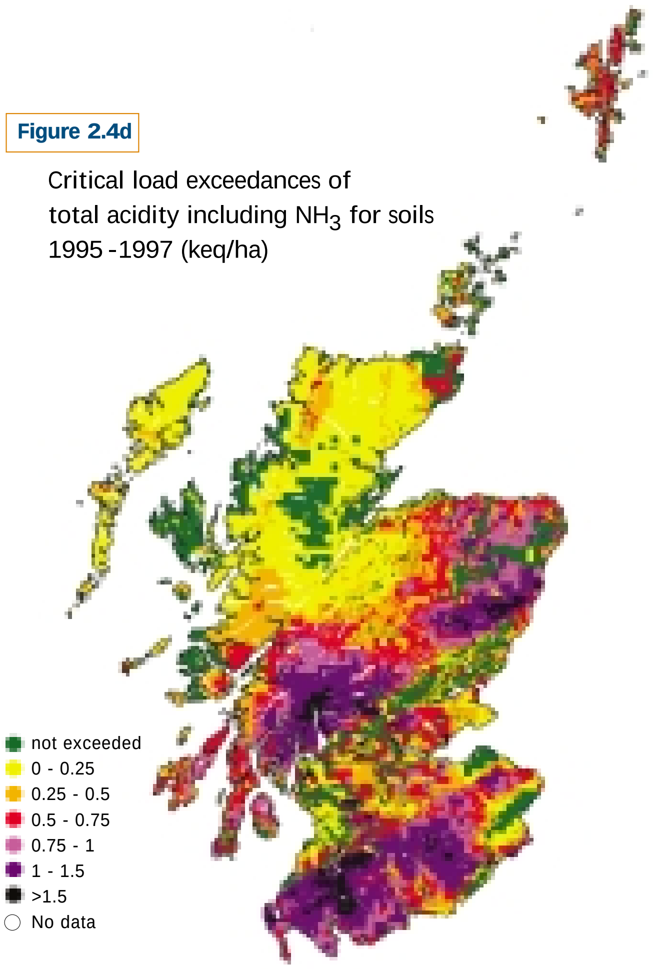
Total acid deposition excluding NH_3 1995 - 1997 (keq/ha)



Source: CEH, MLURI, Aberdeen University

Figure 2.4d

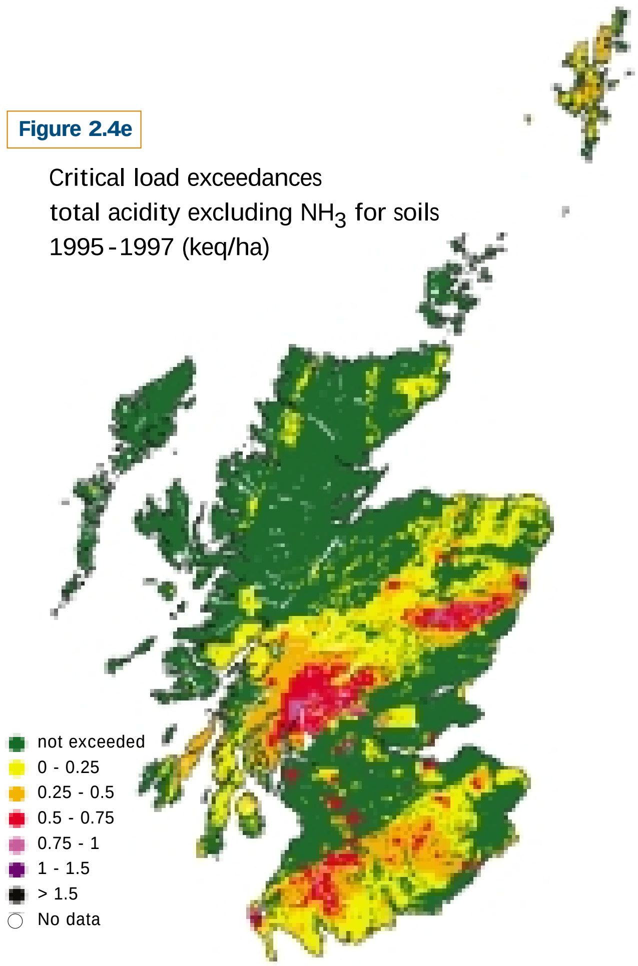
Critical load exceedances of total acidity including NH_3 for soils 1995 - 1997 (keq/ha)



Source: CEH, MLURI, Aberdeen University

Figure 2.4e

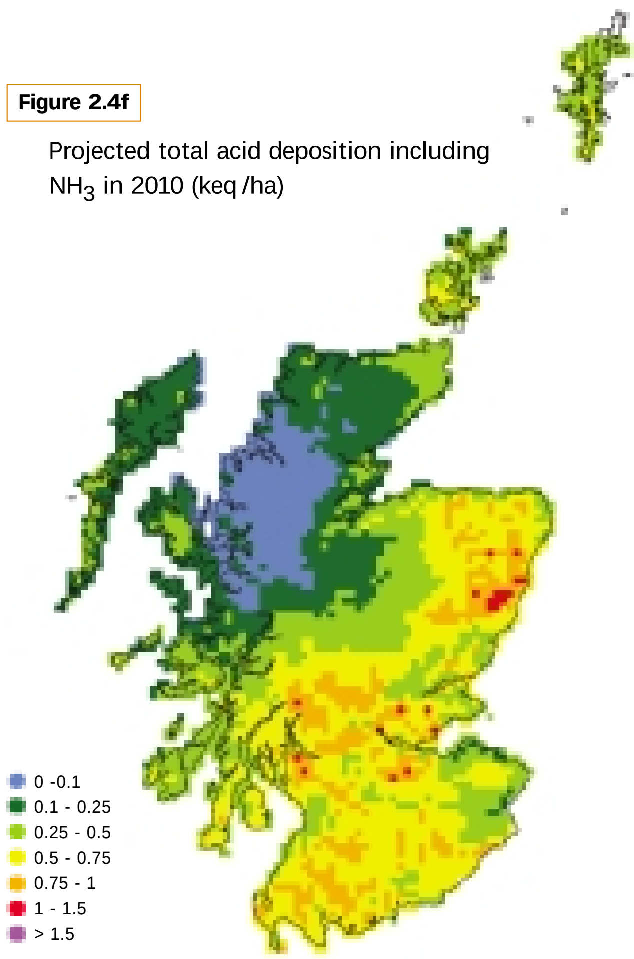
Critical load exceedances total acidity excluding NH_3 for soils 1995 - 1997 (keq/ha)



Source: CEH, MLURI, Aberdeen University

Figure 2.4f

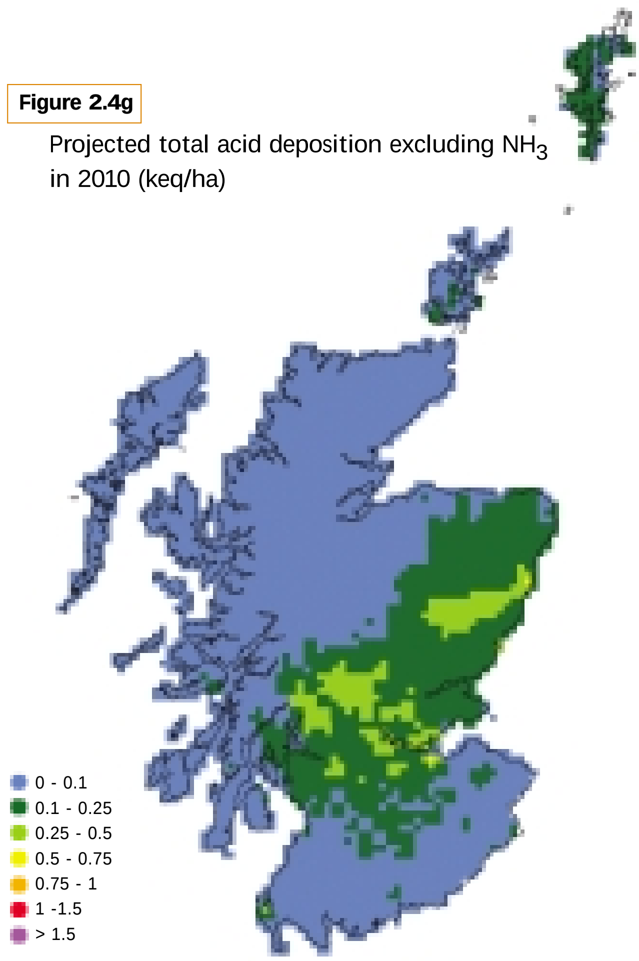
Projected total acid deposition including NH_3 in 2010 (keq /ha)



Source: CEH, MLURI, Aberdeen University

Figure 2.4g

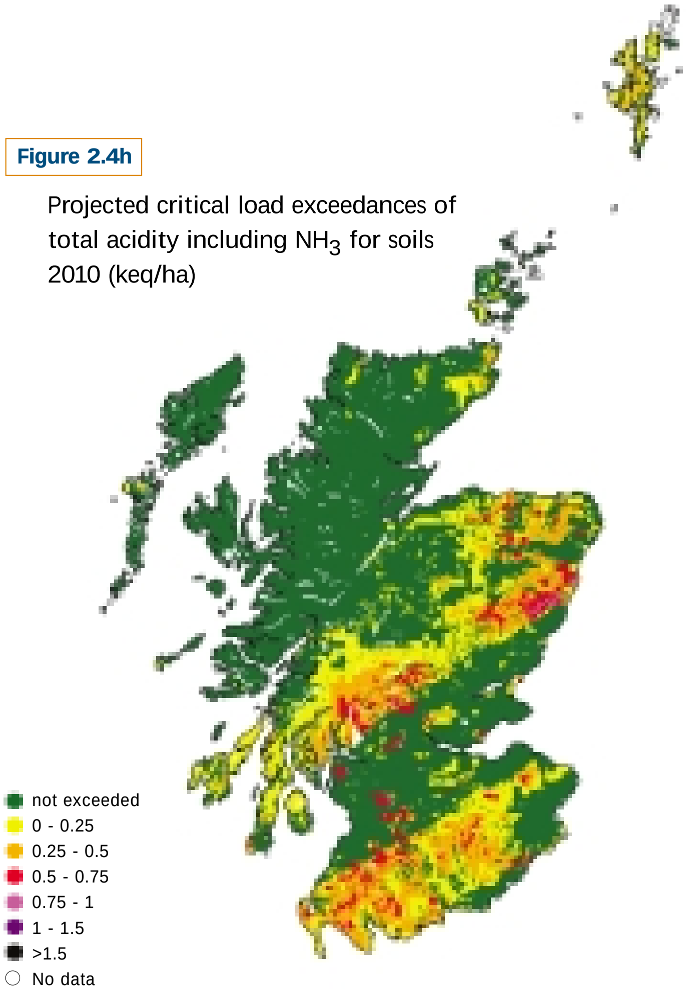
Projected total acid deposition excluding NH_3 in 2010 (keq/ha)



Source: CEH, MLURI, Aberdeen University

Figure 2.4h

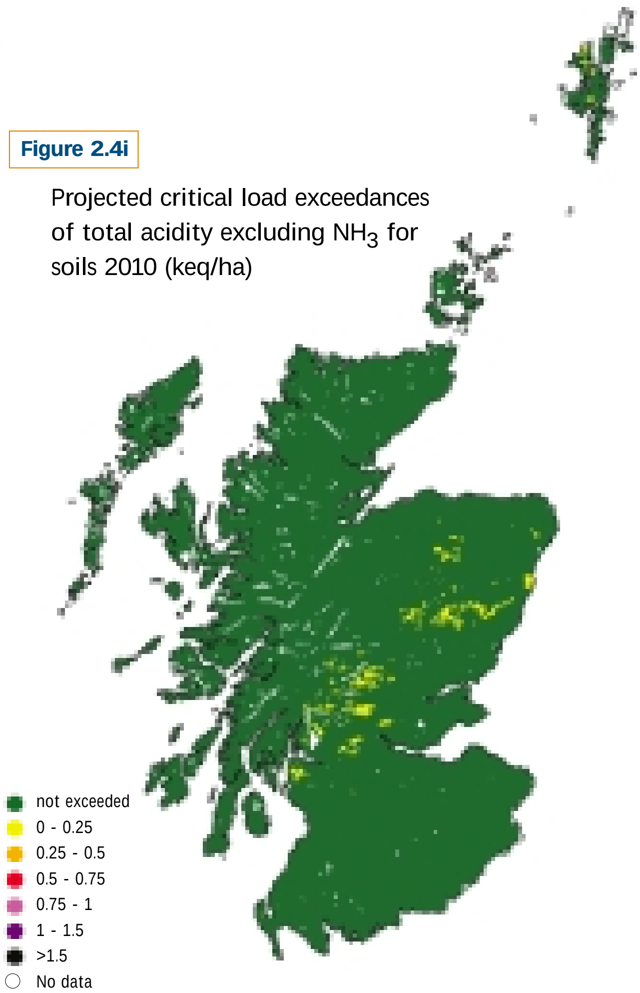
Projected critical load exceedances of total acidity including NH_3 for soils 2010 (keq/ha)



Source: CEH, MLURI, Aberdeen University

Figure 2.4i

Projected critical load exceedances of total acidity excluding NH_3 for soils 2010 (keq/ha)



Source: CEH, MLURI, Aberdeen University

Emissions of total nitrogen, ammonia and oxides of nitrogen from Europe remained stable between 1980 and 1990 followed by a decrease of 15% between 1990 and 1995[37]. Nitrogen deposition rates in Scotland ranged from less than 12 to 24 kg N/ha/y over the period 1992 to 1994[40]. The different distances travelled by reduced and oxidised nitrogen compounds is demonstrated by their deposition and export. Only 25% of emitted nitrogen oxides are deposited within the UK, whereas 66% of the reduced nitrogen emitted is deposited within the UK[40].

Many soils in Scotland, especially upland soils, are shallow and overlay acidic parent material. These soils have limited base cation buffering capacities and are sensitive to acidification from acid deposition. **Figure 2.4a** shows the critical load for acidity for soils in Scotland. The most sensitive soils are in the areas with slowly weathering parent material, notably granites in Galloway and in the uplands.

The total input of acidity from sulphur and nitrogen compounds to the land surface is shown in **Figure 2.4b**, including ammonia and in **Figure 2.4c** excluding ammonia. Ammonia may be immobilised in soil, taken up by plants and trees or nitrified by microorganisms. The contribution of ammonia to soil acidity is not well known and is dependent on soil conditions influencing its microbial turnover. The largest inputs of acidity occurred over Dumfries and Galloway, the west central Highlands and the eastern Cairngorms. Exclusion of ammonia significantly reduced the amount of acid deposition as shown in **Figure 2.4c**. Exceedences of the critical load for acidity in soil are widespread and significant, by over a factor of six in the Galloway hills and the west central Highlands north of Loch Lomond (**Figure 2.4d**). The critical load is exceeded in 85.6% of the land area. Even without the contribution from ammonia the area exceeded is 55.5%, shown in **Figure 2.4e**.

Reductions in emissions of 80% of 1980 levels by 2010 are expected as a result of the UNECE's Second Sulphur Protocol. The acid deposition expected as a result has been modelled for 2010 and is shown in **Figure 2.4f**. A reduction in deposition is clearly shown, especially in the uplands and when the contribution from ammonia is excluded the problems of acidification appear to be largely solved, **Figures 2.4f** and **2.4g**. However, it should be noted that recovery of soils and freshwaters from acidification can be extremely slow and spatially variable, depending on

Upland soils, the Rest and be Thankful, Argyll

the release of alkalinity from soil minerals. In 2010 exceedence is expected to occur in between 3.9% and 39.4% of the land area depending on the contribution of ammonia to acidity (**Figures 2.4h** and **2.4i**).

Information on the recovery of acidified soils is scarce. Models have predicted that current agreed sulphur reductions will have only a marginal beneficial effect on the recovery of soils and surface waters in Scotland[41]. Indeed a continued decline in base saturation is predicted until 2050 for catchments with acid sensitive geology in Galloway and Aberdeenshire.

Evidence of soil acidification has been observed in several parts of Europe, most notably in Germany[42]. In Scotland, increased acidity have been measured in both peat and forest soils. Soil chemical changes including increased acidity have been recorded over a 40 year period in a coniferous plantation in north east Scotland, attributed to a combination of atmospheric pollution, nutrient depletion because of tree growth and natural soil processes[43]. Peat acidification has been found to be correlated with acid deposition across Scotland. The distribution of acid peats was also correlated with the disappearance of acid sensitive lichens[44].

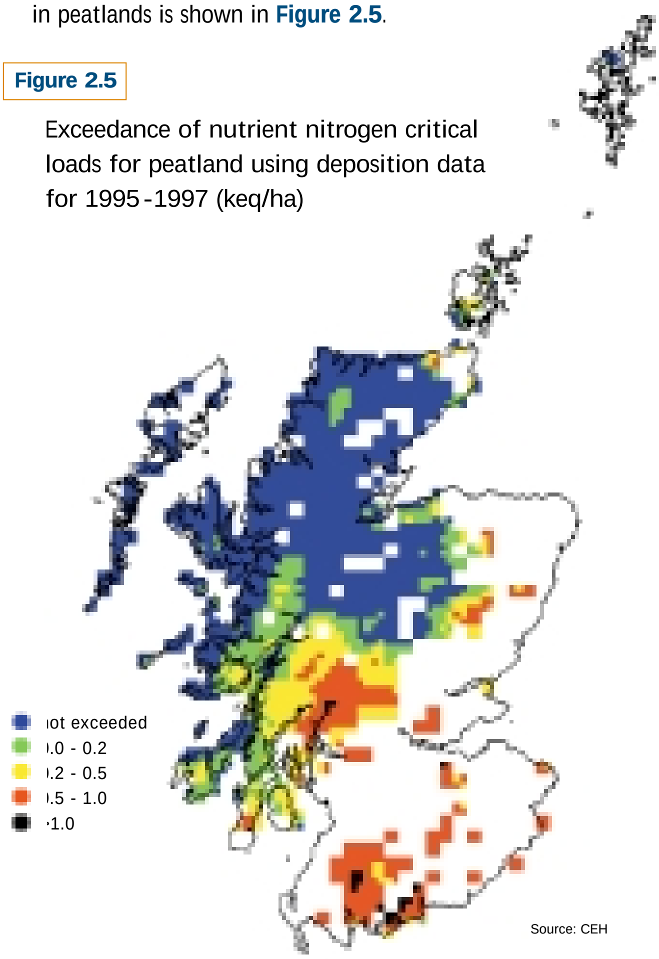
Acidification of soil has a wide range of impacts on ecosystem function and biogeochemical cycling and can also lead to negative impacts on water quality and vegetation health. As a soil acidifies its acid neutralising capability, or buffering capacity, becomes depleted as base cations such as magnesium and calcium, both essential plant nutrients, are leached from the soil. As acidification proceeds metals, including aluminium which is toxic to aquatic life and vegetation, become mobilised.

Reductions in microbial activity, litter decomposition and nutrient cycling then follow, leading to an accumulation of organic matter in soils[45]. Acidification can also lead to vegetation change with the growth of acid-tolerant species at the expense of indigenous vegetation.

Nitrogen deposition also contributes to soil and water eutrophication, as well as to acidification. Nitrogen is an essential plant nutrient. Excess inputs can contribute to soil eutrophication and subsequent vegetation change in nutrient poor environments. Such environments often have a high conservation value. A recent review[46] found evidence of increases in the concentration of nitrogen in plants, reflecting deposition rates for several species, including *Calluna* spp and *Nardus* spp. Reductions in mosses and increases in grasses on *Racomitrium* heath has also been observed. It concludes that nitrogen deposition has contributed to vegetation composition in a range of habitats across Britain. Critical loads for eutrophying nitrogen have been established for several ecosystems and range from 5 kg N/ha/y for ombrotrophic bogs to 35 kg N/ha/y for calcareous grasslands[46]. Exceedance of the critical load for eutrophying nitrogen in peatlands is shown in **Figure 2.5**.

Figure 2.5

Exceedance of nutrient nitrogen critical loads for peatland using deposition data for 1995-1997 (keq/ha)



Elevated nitrogen deposition has also been implicated in forest decline across Europe, although impacts on tree health have not been observed in the UK. Soil carbon and nitrogen status appear to have a major role to play in the fate of deposited nitrogen. Elevated nitrogen inputs can stimulate nitrification and mineralisation rates in soil and inhibit organic matter decomposition rates[47]. Elevated deposition eventually leads to a soil becoming saturated with nitrogen at which point nitrate is leached from the soil contributing to eutrophication of surface waters. The carbon to nitrogen ratio in the soil organic layer can be used as an indicator of nitrate leaching[48]. A survey of nitrate concentrations in surface waters has shown elevated concentrations in Galloway and the Cairngorms, indicating that the soils in these areas are saturated with nitrogen[49].

Soil acidification is a prerequisite of surface water acidification, the principal cause of pollution in Scotland's lochs and the third most important cause in rivers[5]. The West of Scotland is particularly affected, with over 400 km of rivers in Galloway classified as polluted attributable to acidification. The consequences for fish stocks have been severe and incomes from fisheries have fallen dramatically. Widespread coniferous afforestation in Galloway has contributed to the observed acidification. Forests, particularly coniferous, increase the inputs of pollutants to soil due to the large surface area of needles which scavenge pollutants from the atmosphere. This observed acidification indicates that the buffering capacity of these soils has been lost.

SEPA's role

Legislation is being formulated to further reduce the emissions of sulphur and nitrogen containing compounds. The Second Sulphur Protocol came into force in 1998 and takes into account environmental impact as well as the quantity of each country's emissions. The UK has agreed to reduce sulphur emissions by 80% of 1980 levels by 2010. The UNECE Multi-Pollutant, Multi-Effect Protocol and the proposed National Emissions Ceilings Directive set ceilings for national emissions of sulphur dioxide, nitrogen oxides, ammonia and volatile organic compounds to be attained by 2010; the latter as a means of implementing the EU's Acidification Strategy.

SEPA has an important role to play in regulating the emission of sulphur and nitrogen compounds from industry under the Integrated Pollution Control (IPC) and the Air Pollution Control (APC) regimes and the recently introduced Pollution Prevention and Control (Scotland) Regulations (PPC). In addition, SEPA has specific obligations under the Conservation (Natural Habitats etc) Regulations 1994 to protect designated sites under the Habitats and Birds Directives when authorising emissions under these regimes. Emissions of sulphur dioxide and nitrogen oxides from large combustion plants in Scotland have been reduced by 20% and 10% respectively, since 1996. Currently, SEPA regulates emissions from 2,000 APC processes and 200 IPC sites. Under the Pollution Prevention and Control (Scotland) Regulations it is expected that up to a further 600 complex and 1000 less complex installations will be included in this regime by 2007 including, for the first time, intensive pig and poultry installations to reduce ammonia emissions.

A major source of air pollution is from road transport over which SEPA has no regulatory control. However, SEPA does have a responsibility to act as a statutory consultee with Local Authorities to manage local air quality with regard to the National Air Quality Strategy. This strategy sets objectives for eight main pollutants, including nitrogen compounds and sulphur dioxide.

SEPA recently published the *State of the Environment Air Quality Report*[4] and will be producing an inventory of air pollutant emissions from authorised processes. This will allow the relative importance of pollutant sources across Scotland to be assessed, as well as trends in pollutant emissions and evaluation of pollutant control policy.

SEPA has initiated discussions for a research project to develop an Acidification Strategy for Scotland, in collaboration with the Forestry Commission, funded by SNIFFER. This project will investigate remediation of acidified catchments through techniques such as restoring soil buffering capacity and planning forestry cover in sensitive areas. SEPA has also sponsored research through SNIFFER to compile a database of air pollution impacts on habitats and species.

2.4.2 Heavy Metals

The Issue

Heavy metals such as cadmium, chromium, copper, mercury, nickel, lead and zinc occur naturally in soil at levels dependent on soil parent material. Many are essential to living organisms in trace concentrations. However, human activities can cause elevated concentrations and there is a substantial body of evidence to show that soil processes can be adversely affected.

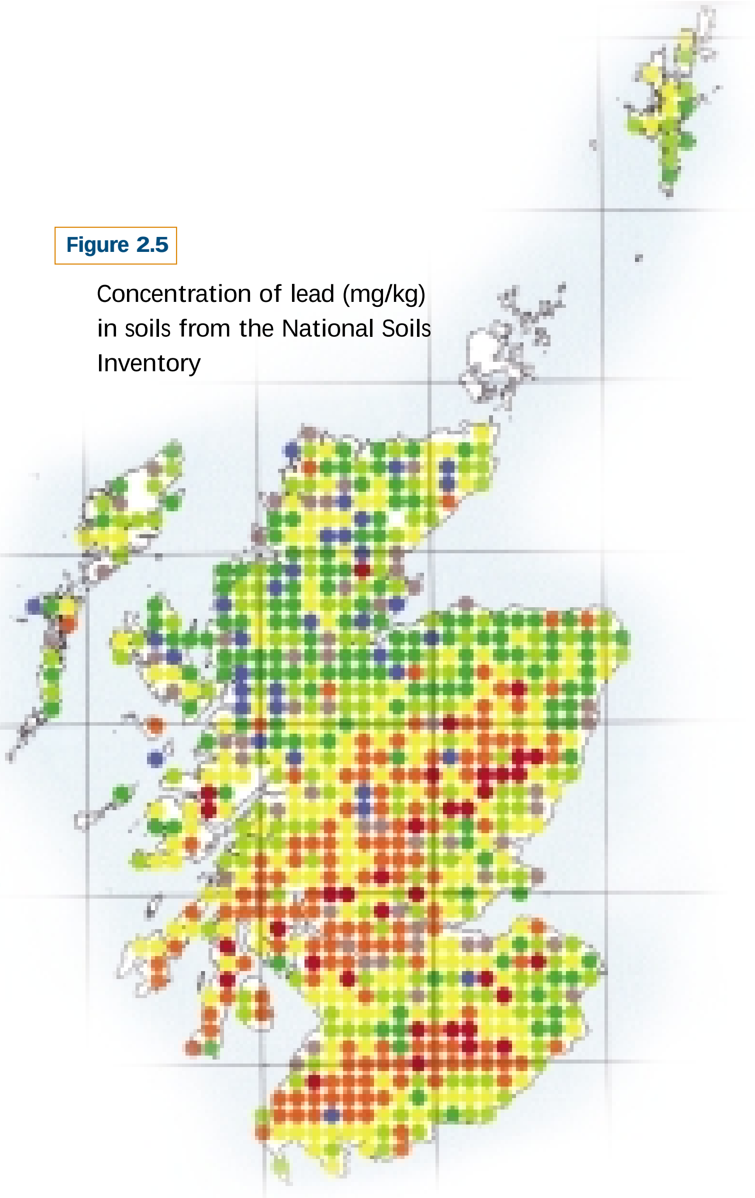
Heavy metals are emitted to the atmosphere from a range of sources including coal combustion, road transport, metal smelting and waste incineration. Despite high localised inputs of heavy metals through application of sewage sludge to agricultural land (see **Chapter 4**) and point source accumulation around industrial sites deposition from the atmosphere represents the most extensive source of heavy metals to soils.

State of the Environment

Modelled deposition rates of heavy metals show that rates in Scotland are at the low end of the range found across Europe for lead, (500 to 2500 g/km^2/y), cadmium (10 to 50 g/km^2/y, although across the central belt rates up to 150 g/km^2/y occur) and mercury (20 to 50 g/km^2/y)[50]. Heavy metal deposition has also been estimated using a technique involving analysis of moss which showed that levels of cadmium, chromium, copper, iron, lead, nickel, vanadium and zinc in Scotland were at the low end of the range for Europe[51].

Figure 2.5

Concentration of lead (mg/kg) in soils from the National Soils Inventory



- Above 168.3 (>95 percentile)
- 60.1 - 168.3 (75 - 95 percentile)
- 28.0 - 60.1 (50 - 75 percentile)
- 16.5 - 28.0 (25 - 50 percentile)
- 7.6 - 16.5 (5 - 25 percentile)
- Under 7.6 (< 5 percentile)
- Non-soil (Urban, rock, etc.)

Source: MLURI

There is currently no comprehensive UK-wide monitoring network for heavy metal deposition and accumulation in soils or vegetation and no detailed systematic study has been carried out to assess the extent of anthropogenic heavy metal contamination in Scotland. However, several studies show the range of heavy metal concentrations in soil. Concentrations in soil profiles from National Soils Inventory (NSI) sites were measured, based on a 10 kilometre grid[52]. Chromium, nickel, copper, zinc, cadmium and lead showed a wide range of concentrations, reflecting the influence of soil parent material and anthropogenic inputs. Results for lead are shown in **Figure 2.5** and for all metals measured in **Table 2.2**.

Heavy metal sources include road transport and coal combustion

Table 2.2

Concentrations of selected heavy metals from National Soils Inventory mineral soils

	Mean mg/kg	Range mg/kg
Cadmium	0.16	0.02 - 0.97
Chromium	44.7	2.3 - 215.8
Copper	9.4	0.19 - 63.9
Lead	31.8	3.9 - 238.8
Nickel	20.5	0.4 - 233
Zinc	53.8	4.0 - 223.6

Source: Paterson, 1999[52]

Cement works and farmland

A geochemical atlas showing the distribution of heavy metals across Scotland is currently being prepared by MLURI.

Heavy metal concentrations have also been measured in upland organic soils across four west to east coast transects following the main geological features of Scotland[53]. Samples were taken from surface soil horizons and therefore reflect atmospheric deposition. Average values for each transect are shown in **Table 2.3**. The smallest concentrations of all metals were found in the most northerly transect and, with the exception of cadmium, largest concentrations were found in the transect 3 which runs across the central belt, most likely reflecting industrial sources and transport.

Table 2.3

Mean concentrations of selected heavy metals from organic soils. See **Figure 2.6** for transect location

	Transect 1 mg/kg North Scotland	Transect 2 mg/kg Central Highlands	Transect 3 mg/kg Central Valley	Transect 4 mg/kg Southern Uplands
Cadmium	0.1	0.8	1.1	1.3
Copper	4.7	8.9	21.6	12.4
Lead	29.0	64.0	180.0	140.0
Nickel	2.2	3.7	21.6	6.5
Zinc	38.0	59.0	94.0	67.0

Source: MLURI

When compared with the limits on heavy metal concentrations set out in the Sludge (Use in Agriculture) Regulations average values for both mineral and organic soils were below maximum permissable limits, although at several individual sites concentrations were above recommended levels, particularly for lead[53,54]. However, when the soil's ability to immobilise metals was taken into account, although lead was found to pose the greatest risk to soil quality on a concentration basis, zinc posed a greater hazard due to its greater mobility compared to the the strong adsorption of lead[13]. Heavy metals mainly affect soil microbial processes which are described more fully in **Chapter 4**.

Another survey using stream sediment data indicated that small areas of Scotland, in Dumfries and Galloway and around Glasgow and Edinburgh, showed above background concentrations of arsenic, cadmium, copper, lead and zinc[54].

SEPA's role

SEPA is responsible for regulating the emission of heavy metals from industry under Part 1 of the Environmental Protection Act. Information on the emissions of heavy metals from industries in Scotland will be compiled in the forthcoming air pollution emissions inventory and the more comprehensive Pollution Emissions Registers being developed under the PPC regime. A number of regulations including the PPC (Scotland) Regulations, the revised National Air Quality Strategy and the 1998 Aarhus EC Protocol on Heavy Metals will reduce emissions further.

2.4.3 Persistent Organic Pollutants

The Issue

Industrial processes can result in the release of a range of persistent organic pollutants (POPs). This report will focus on PCDDs or dioxins (polychlorinated di-benzo-p-dioxins), PCDFs or furans (dibenzofurans), PCBs (polychlorinated biphenyls) and PAHs (polyaromatic hydrocarbons). Dioxins and furans can occur as trace contaminants in manufactured organic chemicals and can be emitted to the atmosphere through combustion processes such as waste incineration. PCBs have been used by industry principally as insulating fluids within transformers and as fire retardants. Their use was phased out in the 1970s. The main source of PAHs is the combustion of fossil fuels and other organic fuel. These chemicals are persistent and have a very long residence time in the environment. All are lipophilic, accumulating in the fatty tissues of living organisms and there is evidence that they have carcinogenic properties. POPs have been implicated in observed toxic effects such as eggshell thinning and reproductive disturbance in several species. For example, PCBs have been implicated in the decline of the European otter and only now are populations beginning to recover.

State of the Environment

It has been estimated that most of the UK environmental burden of PCBs (93.1%), dioxins and furans (95%) is associated with soils[55,56]. Soil has also been identified as an important PAH reservoir[57]. PCBs can evaporate from soil in industrialised countries and be re-deposited in regions remote from sources, a process known as global distillation. There is even evidence of their accumulation in polar regions. Soils are thought to be the main source of PCBs to the UK atmosphere[56]. Modelled deposition rates of PCBs show that rates in Scotland, at 100 to 1000 mg/km^2/y, are at the low end of the range observed across Europe. Deposition rates were largest in Germany at between 5000 and 15000 mg/km^2/y[50]. Deposition rates of dioxins and furans in urban and rural environments are estimated to be 10.2 mg/km^2/y and 4.2 mg/km^2/y respectively[58].

Surveys carried out in England, Wales and southern Scotland[59] showed the ubiquitous nature of background concentrations of PCBs and dioxins in soils, with higher concentrations generally being observed in urban as opposed to rural soils. **Table 2.4** shows the concentration range for total PCBs in soils across the UK. In Scotland an analysis of peat profiles across four transects (**Figure 2.6**) has indicated that greater concentrations are observed in these soils relative to other UK studies[60]. PCB levels were observed to increase from north to south, with the highest levels found in the Southern Uplands reflecting industrial sources in the central belt or Northern England.

Figure 2.6

Concentration of PCBs in upland organic soils

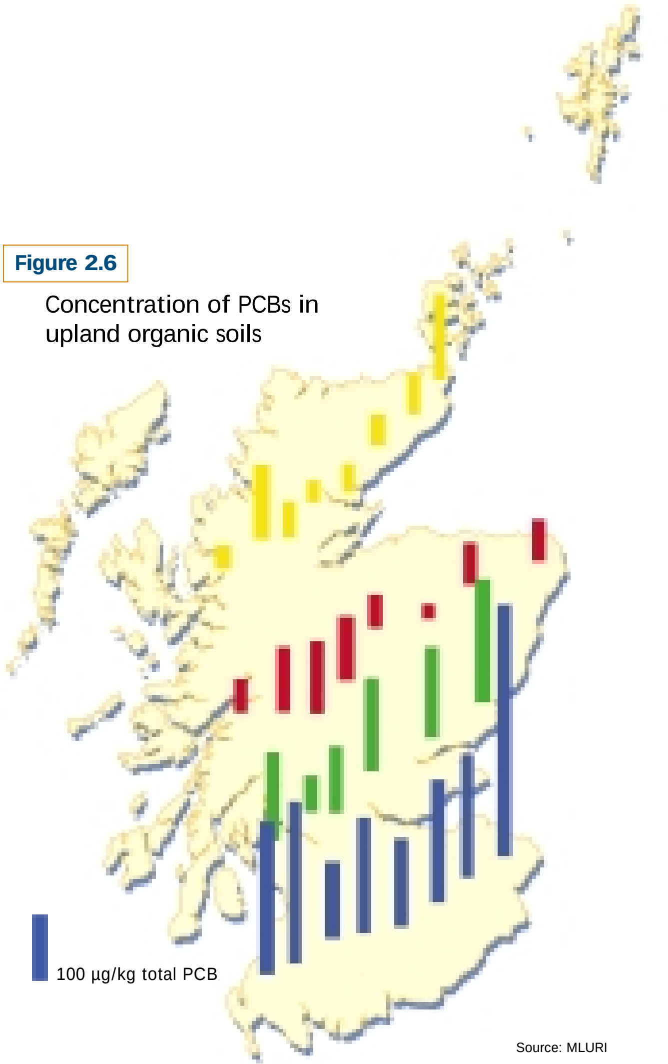


Table 2.4

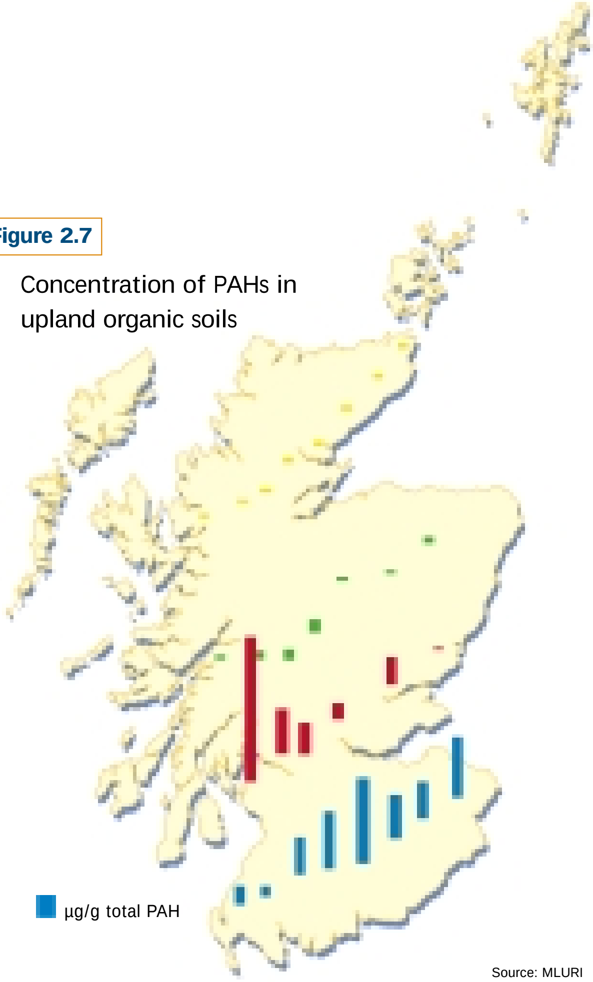
Published soil concentrations of PCBs

	Mean µg/kg	Median µg/kg	Range µg/kg	Reference
UK*	-	30	-	Harrad et al 1994[56]
UK	9.5	6.1	1.7 - 32	Creaser et al 1989[61]
Scotland	10.7	6.0	1.9 - 32	Creaser et al 1989[61]
UK	2.82	2.75	0.33 - 8.7	Lead et al 1997[62]
Scotland	110.8	92.5	62 - 196	Bracewell at al 1993[60]

*estimate based on soil from NW England

Figure 2.7

Concentration of PAHs in upland organic soils



Source: MLURI

Concentrations of PAHs also increased from north to south (**Figure 2.7**), however levels were generally low with the exception of one site which also showed large heavy metal concentrations suggesting a local point source of pollution. An analysis of contemporary and archived (1951-1974) soil samples showed no significant trends in PAH concentrations. Total PAH concentration in Scotland ranged between 20 and 3800 µg/kg. All sample locations were rural and did not include any potentially contaminated sites. The lowest concentrations were observed on rough grazing in the far north west and the largest in grassland south of Glasgow. For the rest of the UK concentrations ranged from 56 to 7400 µg/kg. For dioxins and furans typical concentrations have been estimated at between 1.4 µg/kg[61] and 4.7 µg/kg[58] for urban and at 3.3 µg/kg[58,61] for rural soils.

The impact of POPs on soil processes such as biogeochemical cycling is largely unknown. POPs may be immobilised on the surface of organic matter, degraded by soil microorganisms, volatilised to the atmosphere, leached or taken up by plants. POPs tend to be highly persistent in soils with residence times of over 10 years.

SEPA's role

SEPA regulates the emission of a range of POPs from industrial sources under Part 1 of the Environmental Protection Act 1990 and POPs will be included in SEPA's air emission pollution emissions inventory. The UNECE's Åarhus Protocol on Persistent Organic Pollutants, which was signed in 1998, aims to phase out production and use, eliminate discharges, emissions and losses, and ensure safe disposal methods for a range of substances including PCBs and dioxins. In addition, the EC Directive on the Disposal of PCBs requires equipment containing PCBs to be registered with SEPA and safely disposed of.

2.5 Climate Change

The Issue

Over the next century Scotland's climate is expected to become warmer by between 1.2 and 2.6^{0}C and wetter, with annual rainfall increasing by between 5 and 20%[63]. Regional variations in precipitation are not well defined but it is expected that most of the projected increase will occur in the west of the country whereas some of the east coast may become drier.

State of the Environment

The impact of climate change on soil quality is uncertain and will depend on a number of factors such as the balance between temperature and soil moisture changes, soil type and land use. Changes in rainfall may result in drought or prolonged waterlogging with subsequent impacts on cropping patterns and biogeochemical cycling. Microbial processes are particularly sensitive to

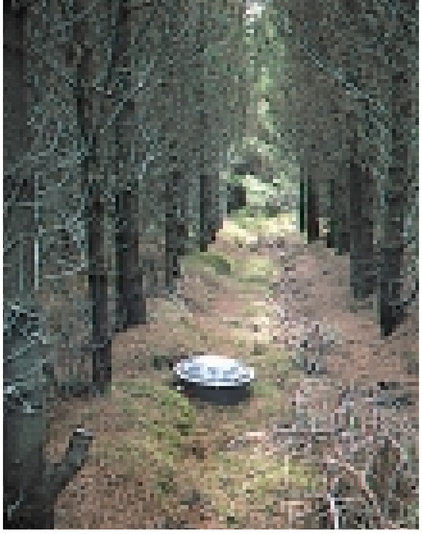
Farmland near Aberdalgie flooded by River Earn changes in soil temperature and moisture and changes in the rate of, for example, nutrient cycling will have potentially important consequences for agriculture, vegetation and the aquatic environment.

A recent scoping study[64] on impacts of climate change in Scotland identified natural resource management as the sector most affected by climate change. Impacts on soils, including increased rainfall and associated nitrogen deposition from the atmosphere, are expected to be associated with changes in the rate of organic matter decomposition and nutrient turnover rates, leading to increased plant growth rates and potential ecological change.

The response of soil organic matter to climate change will have a strong impact on soil processes and the concentration of greenhouse gases in the atmosphere. This is of particular relevance in Scotland given the high organic carbon content of the majority of soils. Upland soils and peats have been identified as particularly vulnerable to losses of carbon and nutrients as a result of increased microbial activity[65]. It is expected that increased rates of decomposition will result in diminished soil organic matter levels and is most likely in regions where organic matter decomposition is limited by temperature[66]. Reduced organic matter levels may also lead to the release of adsorbed chemicals such as heavy metals and pesticides.

The production of both methane and nitrous oxide are strongly dependent on soil temperature and water content, and changes in climate may have feedback effects on soils that make them even larger sources of greenhouse gases. Changes in rainfall will also affect soil quality and soil structure may be damaged by more intensive rainfall events making it more susceptible to erosion.

Elevated atmospheric carbon dioxide concentrations are unlikely to affect soil microbial communities directly because carbon dioxide concentrations in the soil are generally higher than in the atmosphere[67]. However, indirect effects on soil quality may occur through increased vegetation growth leading to changes in litter quantity and quality and subsequent effects on microbial activity and rates of decomposition.



Chamber measurement of methane and nitrous oxide flux in forest planted on peat

SEPA's role

SEPA's *Environmental Strategy* [66] placed global climate change at the top of the list of priority environmental issues facing Scotland. Under the Kyoto Protocol the UK is committed to reducing the emission of six greenhouse gases by 12.5% of 1990 levels by 2012. In addition, a commitment has been made to reduce carbon dioxide emissions by 20% of 1990 levels. SEPA regulates polluting emissions to the atmosphere and therefore has a role to play in delivering UK reductions of greenhouse gas emissions. Specifically, it can regulate carbon dioxide emissions under the IPC regime; and under the PPC regime has powers to ensure that energy is used efficiently. A significant development in this area is the introduction of Voluntary (energy efficiency) Agreements between the UK government and industrial and commercial sectors. In exchange for agreeing challenging energy efficiency targets running to the year 2010, companies will receive an 80% discount on the Climate Change Levy and may be able to satisfy, at least in part, their energy efficiency obligations under the PPC regime. Also significant is the UK government's proposal to introduce a greenhouse gas trading system from April 2001. Both initiatives are expected to lead to significant reductions in the UK's greenhouse gas emissions. Other sources of greenhouse gases are, however, not within SEPA's direct control, for example transport, domestic and agricultural emissions. SEPA has set reduction targets for carbon dioxide emissions arising from its own operations as part of its internal environmental policy.

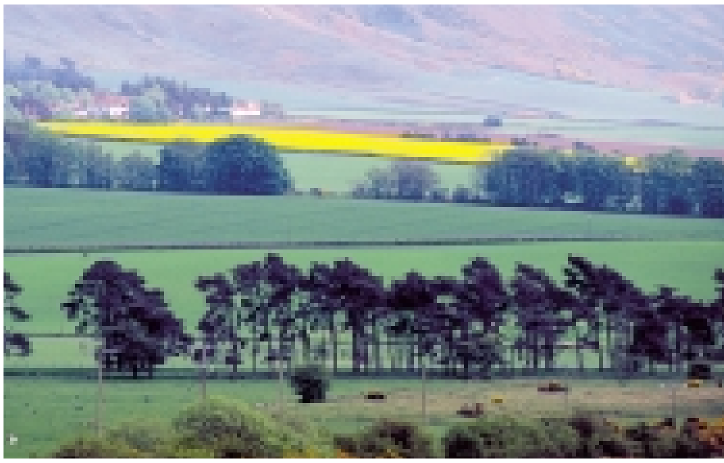
SEPA is involved in the UK Climate Impacts Programme (UKCIP) which aims to examine the impacts of climate change on all sectors of society. The Scottish Executive has recently funded a research project to produce high resolution climate change scenarios for Scotland which will take into account the anticipated large regional variability in climatic change which results from Scotland's varied topography.

3. Impacts of Agriculture and Forestry

Introduction

Agriculture has a dominant influence on the soil resource. About 79% of the land area is classified as agricultural, a relatively large proportion compared to other countries in Europe. Most, 61%, is used for rough grazing with only 8.6% used for cereal production (**Figure 3.1**)[68]. Agriculture in Scotland is restricted primarily by climate and topography with 83% of land being classified as a Less Favoured Area (soil suited only to improved grassland and rough grazing)[68] and only 0.1% of soil being classified as Class 1 (production capability suitable for a very wide range of crops) according to the Land Capability for Agriculture classification scheme[69]. In general, arable farms predominate along the east coast, with grass for livestock dominating in the west and hill sheep production in the north and north west. Agriculture is an important part of the economy and culture of Scotland, accounting for 1.8% of the Gross Domestic Product and directly employing over 25,000 people[69] and, as such, the maintenance of a sustainable soil resource is crucial, particularly at a time when the farming industry is experiencing prolonged economic problems.

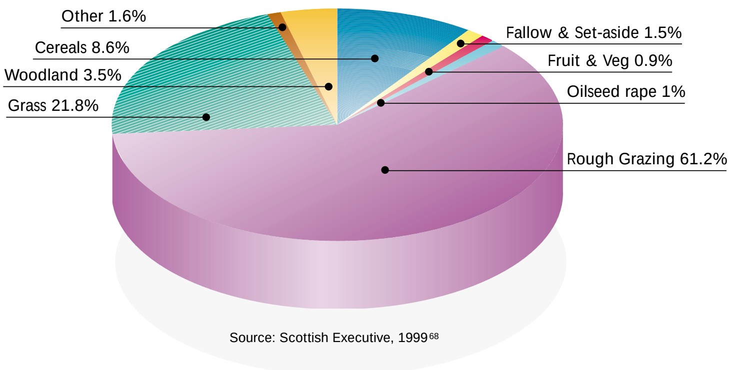
Many agricultural activities have the potential to degrade the soil resource, unless best practice techniques are adopted. Pressures include overgrazing and changes in management practices such as increased mechanisation which may lead to soil erosion, soil compaction and loss of organic matter. Fertiliser and pesticide application may lead to soil acidification, eutrophication and the build up of pesticide residues. As well as impacting on soil quality, these pressures can also result in water pollution through, for example, the run-off of nitrate and phosphorus to surface waters and the potential contamination of private drinking water supplies with pesticides. It is recognised, however, that agricultural production relies on such inputs and that a balance needs to be struck between sustaining agriculture economically and changing land use practices. Farmers themselves have a considerable interest in maintaining soil fertility and ensuring that soil remains a productive resource. Agricultural practices also affect the uptake and emission of greenhouse gases and ammonia.



Arable and hill farming

Figure 3.1

Agricultural land use 1999



Source: Scottish Executive, 1999[68]

SEPA's role in preventing pollution from agriculture is principally concerned with protecting water resources through regulations such as The Control of Pollution Act 1974 (as amended). Diffuse pollution caused by nutrient run-off from agricultural soil is a significant cause of water pollution in Scotland and SEPA has been involved in several initiatives to address the causes of such pollution. Good examples are Loch Leven, the Leet Water and the Dreel Burn in Fife, where catchment initiatives are developing ways to reduce diffuse inputs of silt, nutrients and pesticides to watercourses.

This chapter examines the impacts of agriculture on the soil resource relevant to SEPA's environmental protection activities including erosion and the application of fertilisers and pesticides. Agricultural practices also affect the land-atmosphere exchange of greenhouse gases. Commercial forestry can have impacts on the soil resource with consequent impacts on surface water. Implications of forest practices on soil quality are also discussed. The application of non-agricultural and organic farm wastes to agricultural soil is dealt with in **Chapter 4**.

3.1 Soil Loss

The Issue

Due to the extremely slow rates of soil formation (some soils can take up to 10,000 years to form), soil erosion effectively represents an irreversible loss of the soil resource. Soil erosion occurs through the action of wind and water on exposed soil. It is a natural process which can be exacerbated by human activities including agricultural intensification, overgrazing, drainage and poaching by livestock. The eroded soil frequently ends up in the water environment, with pesticides and nutrients attached to soil particles. This transfer of nutrients into rivers and lochs may cause or promote eutrophication, leading to the growth of opportunistic plant species, particularly algae. Pesticides may cause harm to aquatic organisms and have the potential to pollute drinking water. Erosion can also block drainage ditches, destroy salmon spawning beds and other fish habitats through sedimentation of river beds and cause loss of vegetation on which the river ecosystem relies and which may itself have a high conservation value.

State of the Environment

Soil erosion has been recorded in a wide range of environments, ranging from the Cairngorm Plateau to the arable farms of East Lothian. However, there has been no systematic survey and it is often difficult to attribute a specific cause to individual soil erosion events.

Conditions on agricultural soil which exacerbate erosion include fields with little or no crop cover, compacted soils, inappropriate cultivation of steep slopes and the removal of hedgerows and shelter belts. Sandy soils or soils with low amounts of organic matter are particularly at risk. In addition, the change from spring to winter cropping, driven by the Common Agricultural Policy (CAP), has exacerbated erosion events. There have been a number of studies of localised soil erosion on agricultural land in Scotland following rainfall events. In Perthshire, erosion has been observed in 76 out of 208 fields studied[70]. Land cover type was found to be important, with erosion mainly being observed on autumn sown cereal fields and ploughed land but virtually absent on pasture and stubble fields. A similar study in Angus[11] observed soil erosion in 58 out of the 195 fields surveyed. However, much lower occurrences, 10 out of 265 fields, have been observed in East Lothian after a severe rainfall event[71]. Soil losses following storm events result in typical soil losses of between 1 and 2 tonnes per hectare, although losses of up to 80 tonnes per hectare have been recorded[72]. The nature of the material lost during soil erosion events has not been studied in detail and may have important implications. Soil lost through erosion tends to be enriched with clay minerals and organic matter and its associated organisms. Wind erosion is less common but can be significant in areas such as Strathmore, Moray and Nairn. In addition, farm animals can seriously erode river banks with consequences for water pollution and riparian vegetation. As well as the loss of soil, impacts away from the site of erosion and costs such as infill of drains, blockage of drainage ditches and increased sediment in watercourses can be great.

Soil erosion from grazing sheep

Table 3.1

Regional extent of erosion in upland Scotland

Region	extent of area eroded %
Southern Uplands (east)	3.5
Southern Uplands (west)	1.1
Midland Valley	3.9
Trossachs	7.0
Lochaber	3.2
Central Highlands	5.8
Cairngorms	1.5
Eastern Grampians	8.1
Monadhliath	20.0
North west Highlands (south)	1.5
North west Highlands (central)	8.2
Easter Ross	10.1
Wester Ross	6.9
Caithness	0.5
North west Highlands (north)	6.8
Western Isles	6.0

Source: Grieve et al, 1996[73]

Soil erosion in the uplands is also of concern. A survey in 1995[73] concluded that a significant degradation of the peatland resource was occurring (**Table 3.1**). The greatest extent of peat erosion (20%) was in the Monadhliath Mountains. However, the most severely eroded areas were found in the eastern Southern Uplands and eastern Grampians along with evidence of land management pressure such as grazing and burning. In addition, up to 200 m/km^2 of vehicle tracks were recorded. Overgrazing, which has been largely driven by the CAP, increases the risk of soil erosion. Sheep numbers increased to 9.4 million in 1999[68] compared to 7.6 million in the 1930s and deer numbers have also increased in recent years. In 1998, there were an estimated 710,000 deer in Scotland[74]. Recreational activities can also result in localised erosion. In the Cairngorms, for example, footpath widening affected up to 72 m/km^2[75].

Soil erosion can also result from forestry practices, particularly during planting and harvesting. In the past, significant erosion has been recorded following ploughing of nutrient-poor, thin soils which are sensitive to disturbance and often have very slow formation rates.

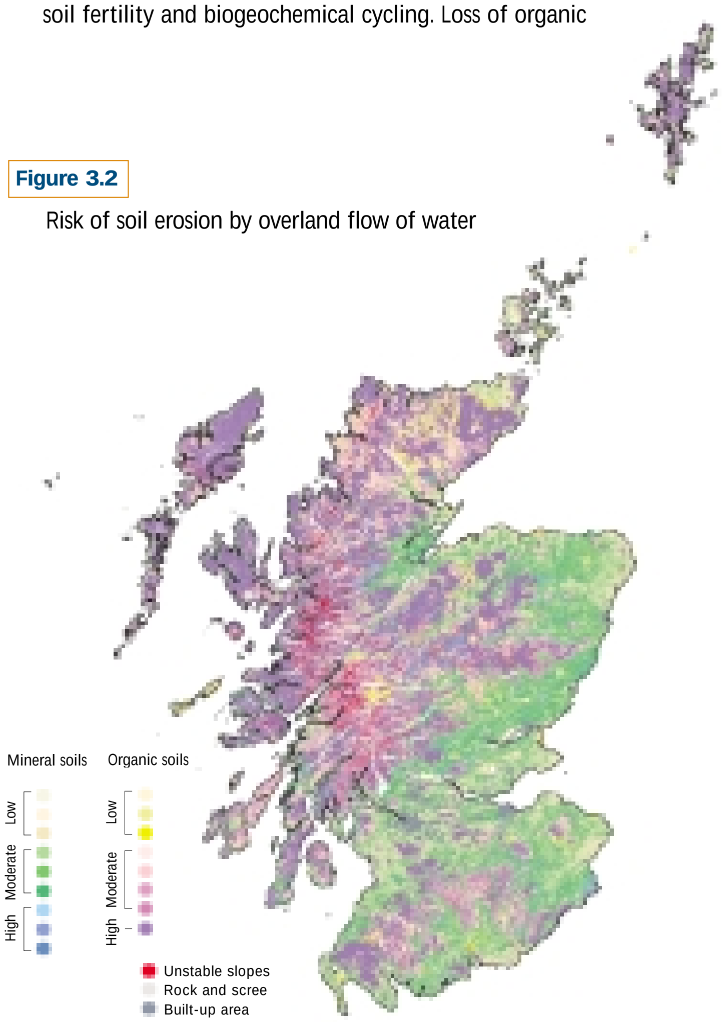
More recently, changes in ground preparation techniques, such as the use of mounding rather than ploughing, have reduced the risk of soil erosion substantially. The Forestry Authority has published guidelines covering many aspects of soil protection and minimisation of soil erosion such as *Forests and Soil Conservation Guidelines*[75] and *Forest and Water Guidelines*[76].

A soil risk erosion map for Scotland based on slope, run-off and soil texture (**Figure 3.2**) has been developed for SNH by MLURI[77]. The model accounts for erosion by overland flow of water only. It classifies over 50% of Scotland as having a moderate inherent risk of erosion and 32% a high risk. Most high risk soils are organic. The model assumes that the soil surface is unvegetated and, therefore, actual erosion events will cover a much smaller area.

Soil physical structure is essential to the maintenance of soil fertility and biogeochemical cycling. Loss of organic

Figure 3.2

Risk of soil erosion by overland flow of water



Source: MLURI, SNH

Commercial peat extraction for fuel

matter and compaction can affect physical properties in many ways, including a decrease in water infiltration capacity and resistance to the exchange of gases. Agricultural activities, such as field movements of farm machinery, tillage operations and trampling by livestock can damage physical structure. Protection of soil structural quality and maintenance of good drainage are particularly important for agricultural soils in Scotland because of the high water content of many soils. Drainage is deteriorating in many areas, due to reduced drainage subsidy since the 1970s and increasingly wet weather. This reduces agricultural productivity and allows soil structure to deteriorate[78]. An examination of 25 years of continuous tillage, or ploughing, compared to zero tillage for cereals on an arable farm south of Edinburgh showed significant physical degradation linked to a 20% decrease in organic matter content and a 28% decrease in total nitrogen content in the tilled field[11]. Agricultural intensification can also affect soil biodiversity, such as bacteria, fungi, protozoa and invertebrates, which is crucial for regulating a soil's physical and biogeochemical functions.

Peat Loss

Peatlands are an important resource in Scotland, both for their conservation and environmental value. It is estimated that 44% of UK terrestrial carbon is contained within Scottish peatlands[79], but they are under threat from commercial extraction for horticulture, drainage, overgrazing, pasture improvement and forestry. However, the Forestry Authority has recently published guidelines[80] on forests and peatland habitats identifying peat bogs where tree planting should be avoided. Domestic peat cutting for fuel is generally viewed as being sustainable[19].

Raised bogs are mainly found in the central belt and the Grampian coastal plain. No completely natural vegetation exists on lowland raised bogs today and of an estimated 27,892 hectares only 2,515 hectares, 9%, of raised bog exhibiting near-natural vegetation remains[81]. Afforestation is the major factor affecting the extent and condition of raised bog. Extraction for horticulture has also had a significant impact. Flanders Moss East near Stirling has the largest continuous raised bog area in Britain.

Scotland has over one million hectares of blanket bog, approximately 10% of the world's coverage. The Flow Country in Caithness and Sutherland is the largest single expanse of blanket bog in Europe. The total extent of blanket bog that has been degraded is not known, although it has been estimated that forestry has had the largest impact with nearly 130,000 hectares, over 12%, being affected[81]. As well as reducing biodiversity, such losses of the peat resource increase the concentration of greenhouse gases in the atmosphere.

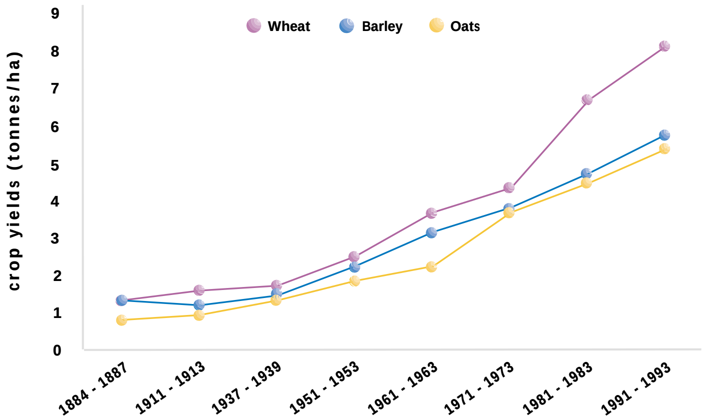
SEPA's role

Although SEPA regards increased erosion in natural soils as undesirable, its role in minimising soil erosion is currently limited, particularly in the uplands. However, SEPA will continue to promote appropriate management practices, through agri-environment schemes and the Scottish Executive's PEPFAA Code (Prevention of Environmental Pollution from Agricultural Activity)[82], to limit the extent of soil erosion. Several of the catchment management plans with which SEPA is involved are promoting methods such as buffer strips to minimise impacts of soil erosion and promote biodiversity. In addition, SEPA's Habitat Enhancement Initiative, which promotes conservation of inland, coastal and tidal waters and associated land, has produced guidance on protecting river banks from erosion by grazing animals[83].

Hand cut and stacked peats

Figure 3.3

Average annual crop yields in the UK (tonnes/ha)



Source: RCEP, 1996[19]

Crop spraying in Fife

3.2 Fertiliser and Pesticide Use

The Issue

Agricultural intensification since the Second World War has resulted in large increases in crop yields (**Figure 3.3**) mainly due to increased reliance on inorganic fertilisers and pesticides. The use of these chemicals can impact on soil quality through changes in nutrient turnover rates, organic matter decomposition rates and the build up of pesticide residues in soil, which may in turn be transferred to the human food chain. Ensuing impacts on the water environment include the leaching of nutrients and pesticides to surface and groundwaters. In addition, the use of nitrogen fertilisers can result in elevated emission of the greenhouse gas nitrous oxide from soil.

3.2.1 Fertilisers

State of the Environment

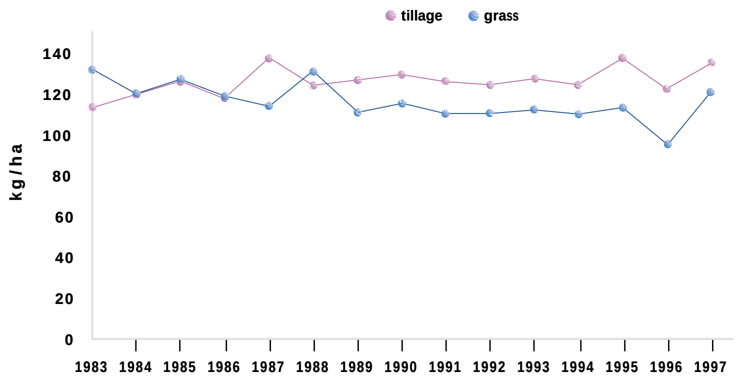
Nitrogen fertiliser is most commonly applied to the soil as a combination of both nitrate and ammonium compounds. Nitrate ions are very mobile in soil and may be leached to groundwater or surface waters when present in excess of the demands of plants and microrganisms. This is in contrast to ammonium ions which may be adsorbed onto soil particles, preventing them being leached, before being transformed to nitrate by microorganisms in the soil. The extent of nitrate leaching depends on soil parameters, soil management and climate, as well as the amount and type of fertiliser applied. Careful management can significantly reduce the amount of nitrate leached. Nutrient inputs may also occur through deposition from the atmosphere, nitrogen fixation within the soil, application of sewage sludge and industrial wastes and mineralisation of soil organic matter.

Soil eutrophication by inorganic nitrogen and phosphate-based fertilisers can have a range of impacts on ecosystem functions. Nitrogen inputs have been shown to increase rates of nitrogen transformations in soils, leading to increased nitrogen losses both through leaching to water and as a gas to the atmosphere[84]. Fungal populations are essential to soil sustainability in both natural and agricultural ecosystems as they enhance plant nutrition and control plant pathogens. Tillage and excessive fertiliser input have been shown to reduce these populations, resulting in an increased reliance on inputs of inorganic fertiliser[85]. Soil structure may also be adversely affected by reductions in soil biota with subsequent effects on chemical and biological processes[86]. Ammonium fertilisers can contribute to soil acidification mobilising metals, such as aluminium, which is toxic to plant roots. In addition, re-establishment of natural or semi-natural vegetation on former agricultural land can be significantly impeded by high soil fertility[87].

Nitrogen applications to agricultural land have ranged between 113 and 139 kg/ha between 1983, when records began, and 1997[87] (**Figure 3.4a**). Rates of application to tillage crops are approximately 40% lower in Scotland than in England and Wales because of differences in cropping practices, such as the greater extent of malting barley and the associated nitrogen requirements[88]. Partly as a result of economic constraints, farmers are becoming increasingly aware of the value of organic wastes and the need to plan fertiliser use carefully. Nutrient run-off from agriculture is a significant cause of water pollution in Scotland. The strong influence of arable cover and associated fertiliser use on water quality is shown in **Figure 3.5** where nitrate concentrations in rivers draining catchments strongly correlate to the percentage arable cover in a catchment[88].

Figure 3.4a

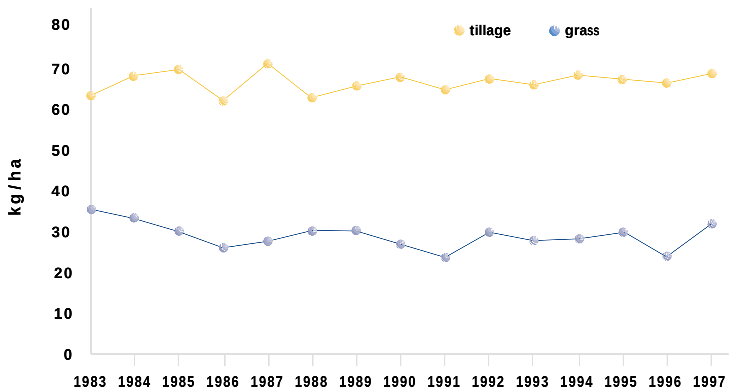
Overall use of total nitrogen (kg/ha) 1983 - 1997



Source: MAFF, 1998[87]

Figure 3.4b

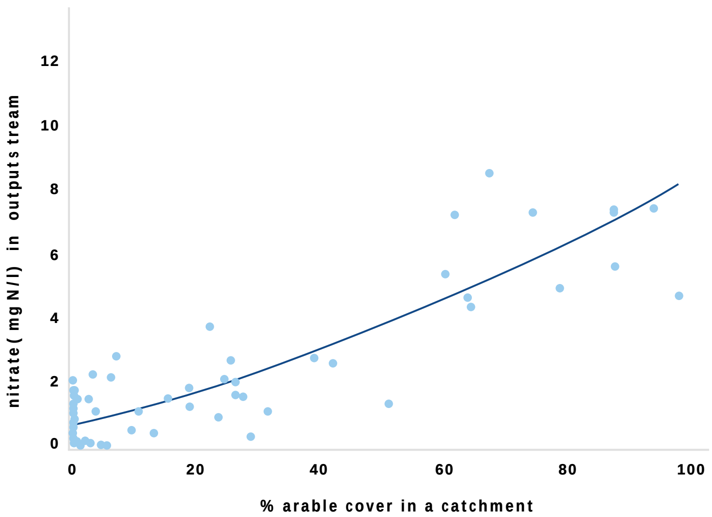
Overall use of total phosphate (kg/ha) 1983 -1997



Source: MAFF, 1998[87]

Figure 3.5

Relationship between the extent of arable cover in a catchment and nitrate concentrations in rivers



Source: Marsden et al, 1997[89]

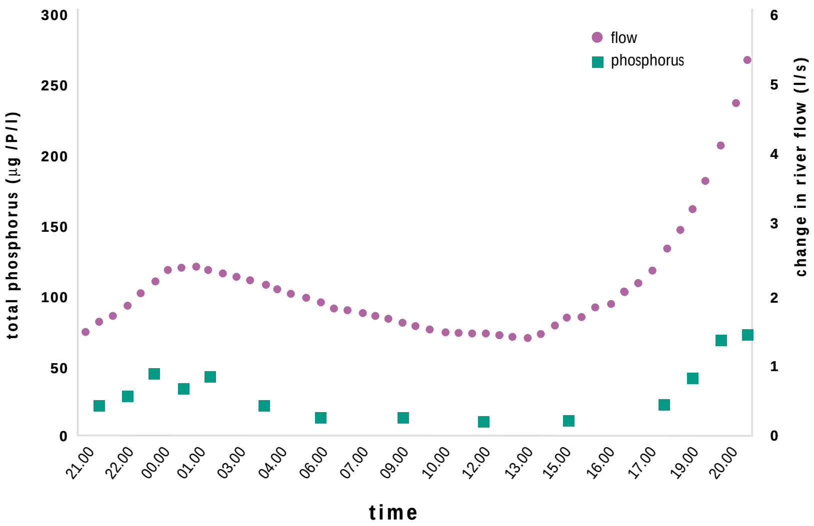
In contrast to nitrate, phosphorus is relatively immobile in soil, being strongly adsorbed to soil particles, so that pollution of surface waters mainly occurs through transport of soil particles by erosion. Application rates of inorganic phosphorus have been fairly stable since 1983 (**Figure 3.4b**)[88]. However, most agricultural land is over-supplied with phosphorus by an estimated 16 kg P/ha/y[91]. This has led to a build-up of phosphorus in soils[92] and to the transport of dissolved as well as particulate phosphorus into surface and ground waters.

The importance of land use and hence soil erosion in the transport of phosphorus to watercourses has been investigated by SEPA[93]. **Figure 3.6** shows the total phosphorus output from a forestry dominated catchment, Malling Burn in the Trossachs, and from an arable dominated catchment, Greens Burn which drains to Loch Leven in Fife. After a storm event, levels of phosphorus increased to 100 µg/l from the forestry dominated catchment compared to nearly 3,000 µg/l associated with high levels of suspended solids, from the arable catchment, clearly showing the impact of land use on soil erosion rates.

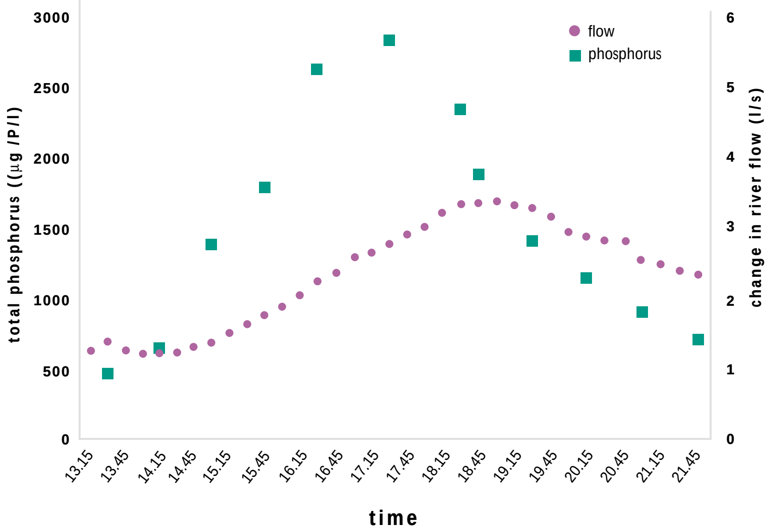
Figure 3.6

Changes in river flow and total phosphorus concentration from a) a forestry dominated catchment and b) an arable dominated catchment during a rainfall event

a) forestry dominated catchment



b) arable dominated catchment



Source: Marsden et al, 1997[89]

Soil nutrient levels, predominantly phosphorus, magnesium and potassium, are routinely measured by SAC as part of its advisory service for farmers. Levels vary according to location and the predominant type of farming[92]. Areas with a high predominance of arable cropping such as in Fife and Lothian have the highest soil nutrient levels whereas the Western Isles and Kintyre have the lowest. Grassland areas and the Highland region have generally low levels of potassium whereas horticultural areas have high levels reflecting potash inputs.

Trends in phosphorus, magnesium and potassium levels were fairly stable between 1986 and 1991[92]. Of the other nutrients measured manganese was the most deficient and both copper and cobalt levels declined over the period 1986 to 1991.

Soil acidity has important implications for fertility and subsequent plant growth. pH levels showed a gradual fall over the period 1986 to 1992 suggesting that adequate lime application had not been maintained[92]. pH levels were also reflected by cropping regimes with the highest levels in the arable fields of Fife, Lothian and the south east and the most acid in the Western Isles and Kintyre where rough grazing on peaty soils predominates. However, it should be noted that these figures, although providing an indication of soil fertility, may not necessarily be representative as soil sampling is not systematic.

Sulphur is increasingly being used as a fertiliser, partly in response to lower sulphur contents of phosphate fertilisers, but also because of reductions in sulphur deposition from the atmosphere. Responses of plant growth to sulphur fertiliser are recorded in cut grassland, oilseed rape and cereals on free draining soils in areas of low atmospheric sulphur deposition, such as north east Scotland.

3.2.2 Pesticides

State of the Environment

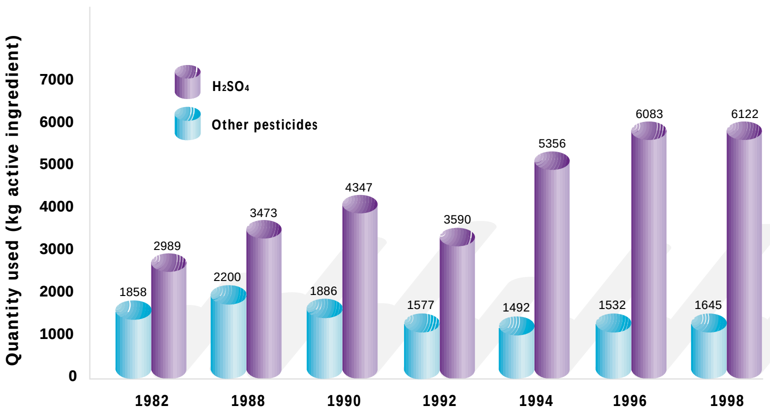
Pesticides used in agriculture include insecticides, molluscicides, fungicides, herbicides, growth regulators and seed treatments and comprise a wide range of chemicals. Over 450 are currently approved for application to arable and horticultural land[88]. Concern has been expressed that the repeated use of pesticides may lead to their accumulation in soil and to damaging effects on the environment. Pesticides can enter watercourses in surface run-off, damaging aquatic ecosystems and polluting drinking water. They may also affect non-target species directly and predators indirectly by eliminating their food sources.

SEPA has detected a range of pesticides, including Triazine herbicides and organophosphate insecticides, in watercourses draining agricultural land[93].

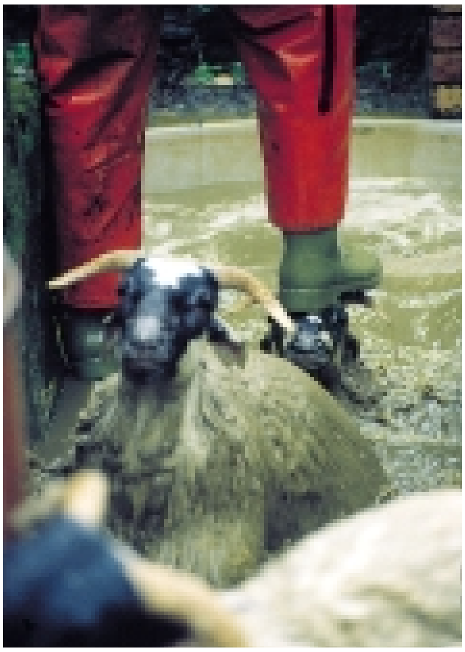
The amount of pesticide applied to arable crops has increased from 4,847 tonnes in 1982 to 7,767 tonnes in 1998 (**Figure 3.7**)[94]. The vast majority of the amount applied (nearly 80%) is sulphuric acid applied to potato crops before harvesting. The observed increase was due to a greater proportion of the potato crop being treated in recent years. Other pesticides decreased slightly over the period possibly reflecting factors such as the use of lower dose biologically active substances and the use of Integrated Crop Management plans[95].

Figure 3.7

Pesticide applied to arable crops 1982-1998



Source: Snowden and Thomas, 1999[94]



Sheep dipping

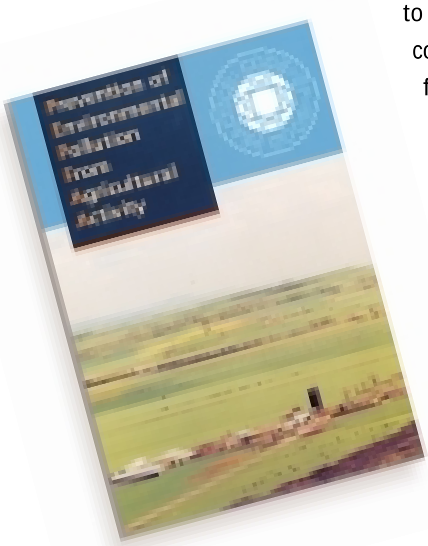
Many soil micro-organisms have the ability to degrade complex chemical compounds including pesticides. However, there have been few studies into the impact of pesticides on soil quality. One long-term study showed that repeated pesticide applications were either rapidly degraded in soil or were bound to soil organic matter and made biologically inactive[96]. There have been reports that some pesticides can modify soil microbial populations so that future applications of the same pesticide are broken down more quickly[19]. Although it is clear that soil can act as a sink for many pesticides, with soil properties determining their persistence and fate, a recent review *Pesticides in the Environment*[95] found no systematic surveys of pesticide residues in soil or their impacts on soil quality.

Although not strictly defined as a pesticide, the use and disposal of sheep dip has caused several serious water pollution incidents. The active ingredients in sheep dip include either organophosphorus compounds which are believed to harm the human nervous system as well as being toxic to aquatic life, or synthetic pyrethroids which are extremely toxic to aquatic life, 100 times more than organophosphates. Under the recently introduced Groundwater Regulations (1998), disposal of waste sheep dip to soil has to be authorised by SEPA. Sheep-dipping chemicals are not readily leached and most suitable soils for disposal are those with a high adsorption capacity and high microbial degradation potential. Soil parameters such as soil type, pH, depth and drainage characteristics are taken into account by SEPA before granting an authorisation for disposal sites. Impacts of organophosphate compounds on soil quality are not well known, however, a recent review[97] suggested that due to their rapid breakdown and low availability impacts on microbial processes and on the microbial community were unlikely in the short term. Over two million litres of sheep dip chemicals were disposed of to soil in 1999 with a wide distribution throughout the country. The impact of other veterinary medicines on soil quality is discussed in **Chapter 4**.

SEPA's role

Current regulations relating to the use of fertilisers and pesticides are principally concerned with protecting the water environment. The recent State of the Environment Report *Improving Scotland's Water Environment*[5] identified diffuse agricultural pollution as a major cause of pollution in Scotland's rivers, lochs and estuaries. Land use management and soil protection are key factors in helping to alleviate this problem. To this end, the EC Nitrates Directive aims to reduce and prevent pollution of ground and surface waters by nitrates. The designation of areas as Nitrate Vulnerable Zones (NVZs) under The Protection of Water Against Agricultural Nitrate Pollution Regulations is one mechanism by which the impacts of nitrates on ground and surface waters can be reduced, by limiting applications of inorganic and organic fertilisers. Action Programme regulations enforced by SERAD are expected to assist in reducing nitrate losses. Although not designed specifically to protect the soil resource, these regulations should have a beneficial effect on soil eutrophication and acidification. There are currently two NVZs in Scotland, the Balmalcolm in Fife and the Ythan in Aberdeenshire.

SEPA supports the measures put forward in the PEPFAA code[82] which gives guidance to farmers on applying fertilisers and pesticides for environmental protection, as well as on soil protection. Sustainable management of soil is encouraged through advice on soil acidification, maintenance of nutrient status and organic matter levels, soil erosion and soil contamination. The guidance in the PEPFAA code is statutory with regard to the Protection of Water Against Agricultural Nitrate Pollution Regulations.



SEPA strongly supports Farm Waste Management Plans and nutrient budgeting to help reduce waste, improve the collection, storage and use of organic farm wastes and to plan for crop nutrient requirements, minimising inorganic fertiliser inputs. SEPA is also involved in catchment management plans, such as for Loch Leven in Perth and Kinross, in partnership with local farmers and relevant public bodies, to alleviate the effects of diffuse pollution. SEPA's involvement in integrated management initiatives is expected to increase with the implementation of the forthcoming Water Framework Directive. Under this Directive, there will be a legal requirement to address all possible pollution sources, including diffuse agricultural pollution, which will have positive implications for soil eutrophication. There are catchment management plans for many other areas of Scotland covering, for example, Loch Lomond, the Rivers Endrick, Almond, Dee and Spey, the Cairngorm Rivers and North East Scotland's rivers.

In seeking to influence farmers' environmental practices, SEPA, SERAD and the Scottish Agricultural College have produced a series of advisory leaflets for farmers to complement the PEPFAA code. Topics include soil protection, fertiliser and pesticide use, diffuse pollution, protecting riverbanks, application of non-agricultural waste to soil and silos and silage effluent. SEPA was also involved as a consultee in the development of the Local Environment Risk Assessment for Pesticides (LERAPS) which determines the buffer, or no spray, zone for pesticide application based on proximity to and size of a watercourse.

3.3 Gaseous Emissions

The Issue

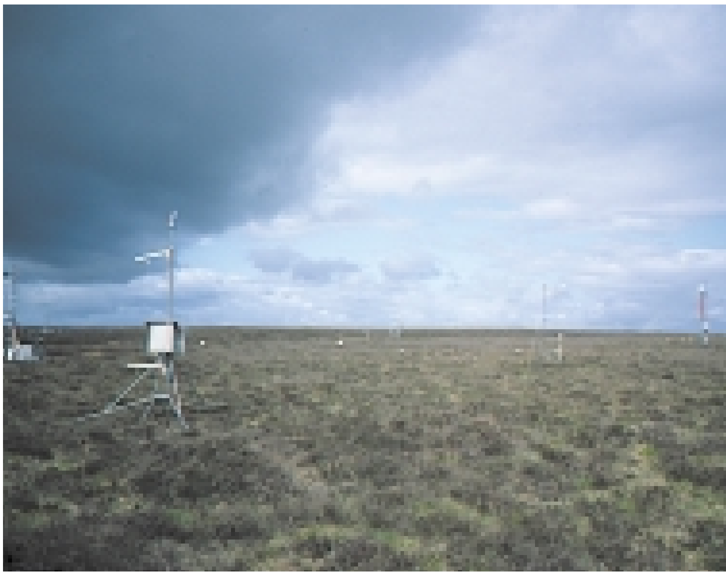
Although not directly related to soil quality, soils play an important role in the emission and uptake of greenhouse gases. The recent Scottish Climate Change Programme[98] estimated that carbon emissions from the agriculture, forestry and land use sector contributed 8.5 MtC or 36% of the total in 1995. A large proportion of this carbon release is from soil. Land use, management practices and application of fertilisers can influence the uptake and emission of the greenhouse gases carbon dioxide, nitrous oxide and methane from soil. It has been estimated that emissions of nitrous oxide and methane from agriculture will account for 63% of non-CO_2 greenhouse gases by 2010[99].

Agriculture is the largest single source of gaseous ammonia emissions in the UK. Deposition of ammonia can contribute to soil eutrophication and acidification. Many semi-natural communities are adapted to low nutrient environments so that eutrophication of soil can lead to vegetation change. The livestock sectors, especially dairy, beef and intensive pig and poultry units, are the largest contributors to such emissions.

3.3.1 Nitrous oxide

State of the Environment

Nitrous oxide is produced by microbial transformations of nitrogen in soils. Emissions from agricultural ecosystems are generally higher than from natural or semi-natural environments[100,101]. The addition of nitrogen fertilisers, timing of application, rainfall, temperature and soil management practices strongly affect the amount of nitrous oxide emitted. In general, larger emissions of nitrous oxide are measured from managed grasslands than from arable soils, as grasslands receive more nitrogen fertilisers, are compacted by grazing animals and commonly occupy wetter, heavier soils with optimal conditions for nitrous oxide production.

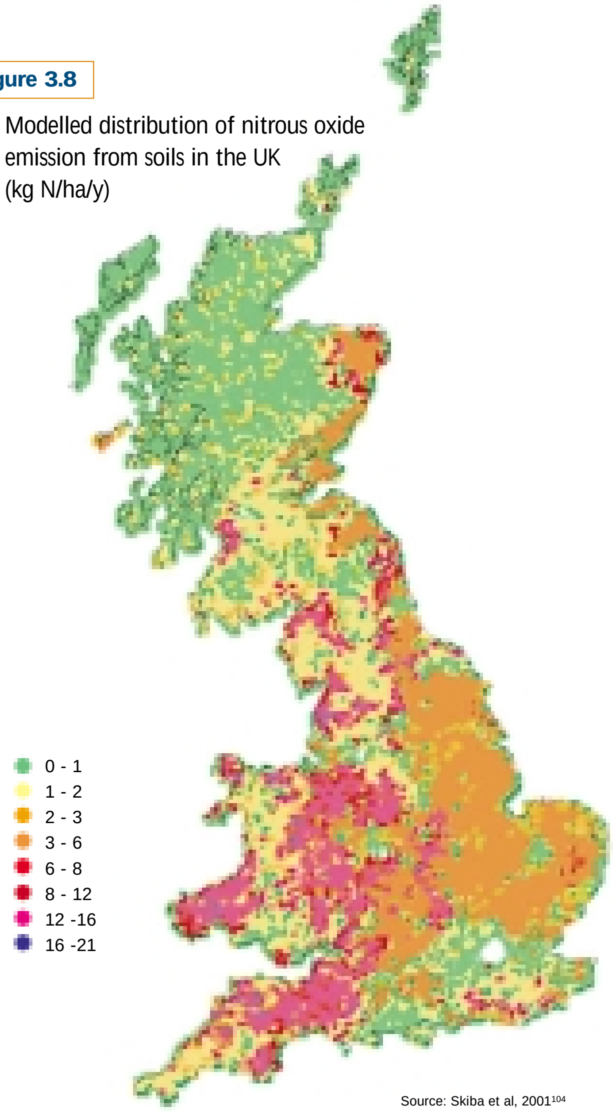


Micrometeorological measurement of greenhouse gases from peatland

Agricultural soil is the largest source of nitrous oxide in the UK, contributing to over 49% of the total source strength[102]. In Scotland the magnitude of the soil source strength is smaller (at 18.9 compared to 147.7 kt/y[101]) owing to the predominance of semi-natural soils in Scotland which represent only a small proportion, around 11%, of the UK source[101]. However, proportionally, emissions from soils dominate, contributing 97% of the total source strength. Vehicle emissions contribute the additional 3%. The distribution of nitrous oxide emission from soils in the UK is shown in **Figure 3.8**. High rates of nitrous oxide emission associated with agriculture can clearly be seen and are estimated to contribute 60% of the total source strength in Scotland[103]. The same biological processes that produce nitrous oxide in soil also produce and emit nitric oxide. Soil is a small source of nitric oxide, compared to nitrous oxide, and contributes less than 10% of the total nitric oxide produced in the UK[104]. In the atmosphere, nitric oxide is a precursor for formation of tropospheric ozone and the nitric acid component of acid rain.

Figure 3.8

Modelled distribution of nitrous oxide emission from soils in the UK (kg N/ha/y)



Source: Skiba et al, 2001[104]

3.3.2 Methane

State of the Environment

Soil can act as both a source and sink for methane, depending on aeration status. Under aerobic conditions soil microorganisms consume atmospheric methane and contribute up to 15% of global methane destruction[105]. Both land use change and the input of nitrogen fertilisers have been shown to affect the amount of methane taken up by soils. The average reduction across Scotland in the rate of methane uptake in agricultural compared to forest soils has been estimated to be 50%[106]. Uptake rates are slow to recover when agricultural land is converted to forestry and can take over 100 years to reach pre-cultivation rates[107].

Under anaerobic conditions such as those found in peatlands, the decomposition of organic matter leads to

Grazing cattle

methane formation. Production rates are strongly influenced by changes in precipitation and temperature. Consequently, human activities such as drainage and afforestation strongly affect the amount emitted. Globally, peatlands are the largest source of methane to the atmosphere but at a UK scale, emissions from human activities predominate. In Scotland, it has been estimated that the largest sources of methane are landfill sites and livestock[108], but peatlands such as the Flow Country in Caithness, the largest expanse of blanket bog in Europe, contribute a significant 17% to the methane budget[109].

3.3.3 Carbon dioxide

State of the Environment

On a global scale, soil is the largest terrestrial sink for carbon. In the UK, an estimated 69% of the carbon storage in soil occurs in Scotland[79]. The soil carbon cycle revolves around the uptake of carbon by plants through photosynthesis, followed by their death and subsequent decomposition by soil microorganisms resulting in the release of carbon dioxide. The rate of organic matter decomposition in soil depends on many factors, including water content, soil physical structure and management practices. Land use change, such as the conversion of forests or grassland to arable use, can result in soils becoming a net source of carbon dioxide to the atmosphere. For example, 85% of the peat soils of East Anglia have been lost as a result of drainage and cultivation, leading to peat oxidation[19]. In Scotland, where most soils are organic, there is potential for land use change to release significant quantities of carbon to the atmosphere.

3.3.4 Ammonia

State of the Environment

Ammonia can contribute both to soil acidification and eutrophication, potentially leading to vegetation change. It can promote losses of nitrate and aluminium into surface waters and lead to higher emissions of nitrous oxide into the atmosphere. The impacts of acidification are discussed in **Chapter 2**.

Agricultural sources make up 90% of the ammonia emissions in the UK[40]. The most important source is animal waste, in particular the land spreading of slurries. Other sources include fertiliser volatilisation and emissions from nitrogen fertilised crops.

Deposition rates of ammonia in Scotland are low relative to the rest of the UK. Estimated inputs between 1992 and 1994 were below 6 kg N/ha/y over most of the country. Larger inputs occurred in Aberdeenshire and south west Scotland, in particular in Dumfries and Galloway where inputs were greater than 14 kg N/ha/y[40].

The deposition of nitrogen can lead to vegetation change as discussed in **Chapter 2**. In addition to diffuse impacts, localised effects of ammonia deposition have been observed. Measurements of ammonia and species composition around four intensive animal units in Scotland showed an adverse effect on species composition associated with high atmospheric ammonia concentrations close to the units. Visible injury to pine and spruce needles was also observed[110]. Deposition of ammonia has implications for designated areas of nature conservation, such as SSSIs. However, it is not yet known how many designated sites are at risk from high localised inputs of ammonia.

Intensive poultry farm

SEPA's role

In its *Environmental Strategy*[21], SEPA identified climate change as the most important environmental issue facing Scotland. However, the role of SEPA in mitigating the emission of greenhouse gases from agricultural sources is limited. The UK government is committed to reducing the emission of greenhouse gases by 12.5% of 1990 levels by 2012. Land management will have an important role to play in conserving current carbon stocks and minimising future emissions of greenhouse gases. Agricultural management practices, such as incorporating cereal straw, no-till farming, agricultural extensification, natural woodland regeneration and bioenergy crop production have a potential to mitigate carbon by 10.4 Tg C/y over the UK[111]. SEPA will promote practices which minimise the loss of greenhouse gases from soil through farm and catchment management plans.

Under the PPC (Scotland) Regulations, emission of ammonia from intensive pig and poultry units over a certain threshold will come under regulatory control for the first time. General Binding Rules are to be approved by Scottish Ministers for these sectors which will aim to ensure that the Best Available Techniques (BAT) are used to prevent the release of potentially harmful substances. In the meantime, SEPA will continue to promote the guidelines set out in the PEPFAA Code[82] for minimisation of ammonia emissions from agriculture.

3.4 Forestry

The Issue

Afforestation has the potential to deliver major environmental benefits. Plantations can act as important wildlife habitats and sinks for carbon. In addition, well designed and sited woodlands increase the diversity of the landscape and contribute to the reduction of diffuse pollution pressure in areas of intensive agriculture. Sustainable forest management can also deliver economic and social as well as environmental benefits.

Forestry on peat soil in the Flow Country

However, commercial coniferous plantations can contribute to soil acidification, leaching of nutrients to watercourses, erosion and physical damage to soil structure. The environmental risks associated with forestry tend to be associated with upland soils which are often nutrient poor, acidic and imperfectly drained. Slow soil formation rates as a result of these qualities and the cool, wet climate makes these soils susceptible to damage and slow to recover.

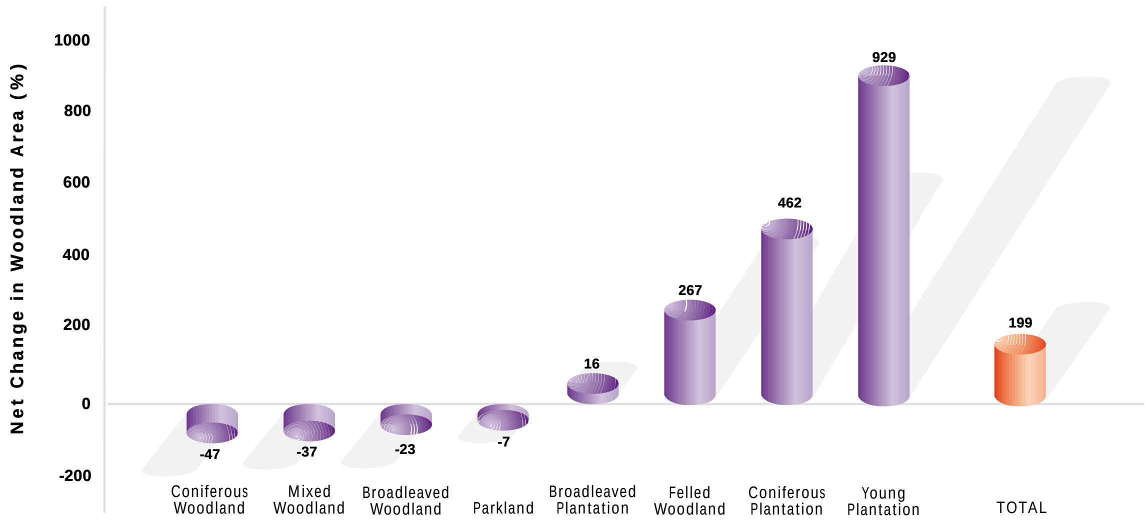
State of the Environment

Clearance of natural forest in Scotland has been occurring for thousands of years until, at the beginning of the 20th century, only 5% remained. The expansion of plantation forest has resulted in approximately 16% of Scotland becoming forested in 1999[112]. This figure is significantly lower than the EU Member States' average of 33%. The Scottish Forestry Strategy[112] aims to support the restoration or create a further 15,000 hectares of native woodland by 2003 and it is expected that approximately one quarter of Scotland will be wooded by the middle of the century.

The net change in woodland between the 1940s and the 1980s, as surveyed by Scottish Natural Heritage as part of the National Countryside Monitoring Scheme[11] is shown in **Figure 3.9**. Broad-leaved and mixed woodlands showed a decline, in contrast to the large increases in young plantation and coniferous forest at the expense of heather moorland, rough grassland and blanket mire. The largest loss of broad-leaved woodland occurred in Grampian and Highland regions, and of mixed woodland in Highland and Tayside regions. The greatest expansion of coniferous plantation occurred in Dumfries and Galloway and Highland regions. Species chosen for new plantations have changed since the 1970s when afforestation was dominated by conifers. By the 1990s, broad-leaved species had increased dramatically from less than 50 to over 500 square kilometres[112].

Figure 3.9

Net change in woodland area between the 1940s and 1980s



Source: Mackey at al, 1998[11]

Afforestation can have a range of effects on soil quality. The presence of a tree canopy alters the microclimate experienced by the soil. Temperatures are generally lower in a forest and transpiration and interception of rainfall by the canopy result in drying of the forest floor. Both temperature and soil moisture content strongly influence soil microbial processes. Planting and felling operations can damage physical, chemical and biological components of soils if not properly managed. Clear-felling results in soil disturbance, erosion, compaction and nutrient loss. In addition, the disturbance caused can result in the oxidation and loss of soil organic matter, resulting in the emission of carbon dioxide. The extent of clear-felling is now limited and guidelines exist to minimise the damage to soil.[75]

Afforestation also affects the amount and type of organic matter in the soil with subsequent impacts on microbial processes, such as decomposition rates and

Larch plantation looking towards Loch Duich

nutrient cycling. In general, coniferous afforestation increases the amount of organic matter in soil due to the recalcitrant nature of conifer needles. In addition, growing trees take up alkaline or base cations from soil, contributing to acidification. The impacts of soil acidification are discussed in **Chapter 2**.

Forests can contribute to carbon sequestration, or lock up carbon. However there is uncertainty about the effect of afforestation on organic soils and there has been much debate surrounding the carbon balance of afforested peatlands. Draining and planting trees on organic soils results in the oxidation of organic matter and the subsequent release of carbon dioxide, potentially offsetting the carbon taken up by the trees. A recent estimate of the carbon balance due to land use change and forestry[79] showed that, although forestry played an important role in carbon sequestration, this may be offset by emissions of carbon dioxide from soils as a result of land use change. However, recent measurements have indicated that, although initially a net source of carbon dioxide, forested peatlands do become net sinks or stores[112]. However, the net balance will depend on second rotation practices and the fate of felled wood. If the potential of trees to sequester carbon is to be maximised, land use decisions must be made to minimise carbon losses from soils.

SEPA's role

SEPA's main interest in forestry practices has been in protecting the water environment, mainly from problems associated with fertiliser and pesticide use, soil erosion and acidification. SEPA has also been involved in the development of the Scottish Forestry Strategy[113]. The main identified priorities which could benefit the soil resource include:

- developing forests of mixed species,
- extending and enhancing native woodlands,
- providing aid for the recovery of acidified rivers and lakes (including intervention measures to restore buffering capacity of acidified soils) and
- encouraging alternatives to clearfelling.

SEPA also promotes the *Forest and Water Guidelines*[76] and the *Forests and Soil Conservation Guidelines*[75].

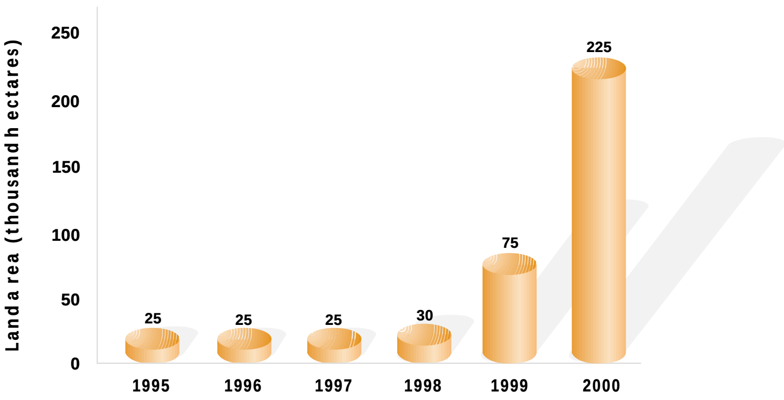
Alternative Farming Systems and Protected Areas

Environmental problems associated with intensive agriculture have been recognised and in response several initiatives are taking place. The agricultural industry is responding to retailer and consumer demand for products from less intensive, integrated or organic farming. Integrated Crop Management (ICM) encompasses a range of practices, such as crop rotation, minimum tillage and optimisation of agrochemical input, designed to make farming more sustainable. Organisations such as LEAF (Linking Environment and Farming) encourage the implementation of ICM through demonstration farms. Organic farming aims to promote sustainable agriculture without the use of synthetic pesticides and fertilisers. It has beneficial effects on farmland biodiversity[114] and the UKROFS standards aim to promote "the management of the soil to encourage the natural biological processes to develop soil structure, fertility and the supply of plant nutrients"[115]. The Scottish Executive operates an Organic Aid Scheme which pays farmers for a five year period of conversion to organic production. The area of land farmed organically has increased significantly in recent years to over two million hectares in 1999 (**Figure 3.10**).

Agri-environment schemes, such as the Environmentally Sensitive Areas (ESA) Scheme and the Countryside Premium Scheme, provide payments to farmers to adopt environmentally friendly practices. There are currently ten ESAs covering 1.4 million hectares or 19% of the land area. In addition, the Farm Woodland Premium Scheme offers annual payments for planting forests on agricultural land. The ESA and Countryside Premium Scheme are due to be merged to form the forthcoming Rural Stewardship Scheme. Reform of the Common Agricultural Policy, Rural Development Regulation and cross compliance measures are all opportunities to integrate environmental interests in to agricultural production. There are opportunities for paying farmers to render a service to and for the environment rather than receiving direct payments for activities that may inadvertently be putting the environment at risk.

Figure 3.10

Organic Aid Scheme uptake 1995-2000



Source: Scottish Executive

Significant areas of land within Scotland (**Table 3.2**) are protected through a range of designations as a result of their natural heritage value, habitat value for rare species, natural beauty and nature conservation. No SSSIs have been selected on the basis of their soil type, however, most are represented within the existing SSSI network[116]. Despite their protected status damage to SSSIs was recorded by SNH on 26 sites covering over 400 hectares in 1997[10]. Damage by agricultural activities affected the largest area (377 hectares).

Table 3.2

Statutory Protected Areas as of 31 March 1999

Statutory Protected Area	number	area ha
Sites of Special Scientific Interest	1,448	919,597
National Nature Reserves	71	114,277
Local Nature Reserves	29	9,297
Special Protection Areas	103	372,261
Special Areas of Conservation	128	643,484
Ramsar Sites*	48	233,886

* internationally important wetlands.
Note statutory protected areas may overlap

Source: SNH, 2000[131]

4. Impacts of Waste Application to Land

Introduction

There are both environmental benefits and problems associated with the application of organic wastes to land. If managed correctly wastes can add significant quantities of nutrients and organic matter to soil, thereby improving soil fertility. However, there are a range of contaminants in many wastes, such as heavy metals and pathogens, which have the potential to pollute soil and watercourses and harm human health. With the exception of sewage sludge there is very little information on the long-term impact of these wastes on soil quality and sustainability.

SEPA is responsible for regulating application of organic waste to land through, for example, the Sludge (Use in Agriculture) Regulations (1989) and the Waste Management Licensing Regulations (1994). However, waste products are disposed of to land with widely varying degrees of regulatory control and although the Sludge (Use in Agriculture) Regulations (1989) do protect soil from heavy metal pollution, there is more emphasis on protecting the water environment and plant, animal and human health.

This chapter discusses the application of organic wastes (namely sewage sludge, industrial wastes, agricultural wastes and composted waste) to land and their impact on soil quality. The impact of landfilling waste is also covered.

Table 4.1

Summary of the beneficial effects of soil organic matter on soil fertility and crop production

	Effects of organic matter
Chemical properties	increased nutrient retention
	increased buffer capacity
	slow release of nutrients
	addition of readily available nutrients
	adsorption of agro-chemicals
	chelation of inorganic toxins
Physical properties	improved aggregation
	increased structural stability
	reduced soil erosion losses
	reduced plasticity of heavy soils
	increased water retention
	increased absorption of solar radiation
	reduced soil strength
Biological properties	stimulated microbial activity
	food source for invertebrates
	release of growth regulators and promoters

Source: Adapted from SNIFFER, 1999[117]

4.1 Organic Wastes

The Issue

Organic wastes applied to land can have positive beneficial effects on soil quality. Many wastes contain significant quantities of nitrogen and phosphorus which can improve fertility and organic matter which can improve soil condition. The beneficial effects of soil organic matter on soil fertility and crop production are described in **Table 4.1**. Other benefits include decreased dependence on chemical fertilisers and their associated costs, reduced transport requirements to licensed disposal facilities and decreased dependence on landfill.

However, there are several potentially harmful impacts on land, air and water. The best documented impact is on the water environment where pollution incidents are caused by spillage or seepage from stored wastes, or application during or soon after rainfall. There are also longer-term effects due to diffuse pollution, one of the principal causes of water pollution in Scotland[5].

Spreading manure

The impact on soil quality is less well known. Most research has concentrated on heavy metals from sewage sludge. Organic wastes may also contain organic compounds and pathogens, the impacts of which have not been fully investigated. In addition, the application of organic waste to land releases various gases to the atmosphere, including ammonia, methane and nitrous oxide, which contribute to acidification and climate change.

State of the Environment

The vast majority of organic waste applied to land in Scotland is agricultural waste, comprising manures, slurries and silage effluent. In contrast, sewage sludge represents only 1% of the total, although this is projected to rise in the future. Current estimates of the tonnage of waste applied to land in Scotland[117] are shown in **Table 4.2**.

Table 4.2

Estimated tonnage of waste to land

waste type	amount wet tonnes	%
agricultural waste	15,000,000	96
exempt industrial waste	367,000	3
sewage sludge	185,000	1
composted waste	-	<1

Source: SNIFFER, 1999[117]

4.1.1 Sewage Sludge

In 1996-1997 only 185,000 wet tonnes of sewage sludge, or 19% of the total produced, was recycled to land[117]. This is expected to rise to over 858,000 wet tonnes by 2005-2006 as a result of additional sewage treatment and the ban on dumping sludge at sea under the Urban Waste Water Treatment Directive. Most sludge is likely to be applied to agricultural land. The water authorities are responsible for monitoring sewage sludge and soils to which sludge is applied under the Sludge (Use in Agriculture) Regulations (1989). The regulations are designed to limit accumulation of heavy metals in soils although UK limits are amongst the least stringent in the EU. However, a MAFF funded review[118] into impacts of heavy metals on soil fertility concluded that current metal limits adequately protect soil micro-organisms with the exception of zinc concentrations, which were recommended to be reduced. This was accepted by the government but on an advisory rather than statutory basis. The maximum permissible levels of heavy metals depend on soil pH as shown in **Table 4.3**.

Table 4.3

Maximum permissible concentration limits for potentially toxic elements (PTEs) in sludge treated soils from the Sludge (Use in Agriculture) Regulations 1989

PTE	pH 5.0 - 5.5	pH 5.5 - 6.0	pH 6.0 - 7.0	pH >7.0
Zinc	200	250	300	450
Copper	80	100	135	200
Nickel	50	60	75	100
	pH 5.0 and above			
Cadmium	3			
Lead	300			
Mercury	1			
Chromium	400 (provisional)			

At present sewage sludge is applied to just over 4,000 hectares of agricultural land at 597 sites. Most sludge is recycled to arable farmland (2,815 hectares, 378 sites) and a smaller amount to pasture (1,389 hectares, 219 sites)[119]. The suitability of land for receiving sludge, depends not only on pH and metal content as discussed above but also upon the soil type and topography.

Table 4.4

Typical concentration of metals in Scottish soils and sludges and the number of applications to raise uncontaminated soil up to the maximum acceptable concentration.

	Zinc Zn	Copper Cu	Nickel Ni	Cadmium Cd	Lead Pb	Mercury Hg	Chromium Cr
Typical sludge metal concentration (mg/kg)	630	300	30	3	270	2.2	55
Normal soil concentration (mg/kg)	80	20	25	0.5	20	0.1	50
UK Maximum allowable soil concentration, pH 5.5 - 6.0 (mg/kg)	200	100	60	3	300	1	400
Number of applications to reach limit value	113	160	700	500	553	245	3,818

Source: SEPA, 1998[120]

A recent study[121] has shown that the majority of soils in Scotland which may receive sewage sludge in future have a strong or very strong metal binding capacity. However, soil pH must be maintained at current levels for this to be sustained.

Typical concentrations of a range of heavy metals in soil and sludge are shown in **Table 4.4**, with the number of applications of sewage sludge which raise levels up to the limits set out in the regulations. Under the present monitoring system applications of sewage sludge are ceased before the concentrations of heavy metals laid out in the regulations are met. Only one exceedance of limits, which was in Ayrshire, has been recorded by SEPA. Changes in land management, where liming of the field had stopped, resulted in a decrease in soil pH, so that cadmium concentrations exceeded the maximum permissible concentration for soil with a pH less than 5.

Sewage sludge contains a wide range of compounds which may be detrimental to soil quality. Most attention has focused on the build up of heavy metals in soils. Whereas generally the addition of organic matter from sludge improves soil condition, the build up of heavy metals can impact on microbiological processes such as nutrient turnover and organic matter decomposition. Heavy metals accumulate in topsoil as they are not readily leached and the amounts taken up by crops are generally small. This capacity to lock up heavy metals is finite, dependant on soil properties such as organic matter, clay content and pH, so that the application of sludge to land has consequences for soil sustainability. Soil microbial biomass is critical to the breakdown of organic matter and the cycling of nutrients. The presence of heavy metals has been found to decrease microbial biomass and respiration in a range of soil types[122]. In one study the effect was detected 20 years after the last application of sewage sludge[120]. However, a large disparity has been reported in the concentrations at which metals in soils are toxic to micro-organisms and the MAFF review[118] on impacts on soil fertility found that negative impacts on soil microbial biomass occurred at concentrations greater than current UK limits (with the exception of zinc, see **section 4.1.1**).

Sewage treatment works

Sewage sludges may contain a range of organic compounds such as benzene, lindane, dialdrin, endocrine disrupting chemicals, phthalates, phenols and surfactants from detergents. Associated problems include leaching losses, persistence in the soil, and toxicity to grazing animals and soil biomass. However, in general, the effects of these compounds on soil properties and organisms are not well known. Although the potential risk posed by these organic compounds is thought to be low, the uncertainty of their fate and rate of breakdown and the lack of current UK standards in soils demonstrates a need for further research.

Sewage sludges may also contain a range of pathogens which pose a potential risk to humans, crops and grazing animals. Despite this risk there have been no reported incidences of links between disease and the application of sewage sludge to land[19]. The application of untreated sewage sludge to food crops was phased out under a voluntary agreement in 1998.

4.1.2 Industrial Wastes

A range of non-agriculturally derived wastes, often referred to as industrial wastes, are applied to land under legal exemptions from waste licensing. In order to satisfy the criteria that these wastes are exempt it is essential that their application provides agricultural benefit or ecological improvement, however, these terms are not defined in legislation. The most common industrial wastes applied to land in Scotland include distillery waste, blood and gut content from abattoirs and paper waste. The actual amounts of waste applied to land are not known accurately. Figures collated from SEPA records[117] give a total 368,000 wet tonnes (**Table 4.5**). The potential maximum amount applied to land shows a wide geographical variation. Almost 290,000 tonnes was applied in SEPA East Region, 60,000 tonnes in SEPA West Region and 14,000 tonnes in SEPA North Region. Records are not readily available for the total areas of land to which wastes are applied.

There are very few data on the impact of industrial wastes on soils and soil processes. It is known that waste with a high Biochemical Oxygen Demand (BOD) can cause anaerobic conditions in soils. Wastes such as papermill sludge, can have limited benefit due to high carbon:nitrogen ratios which can result in nitrogen being locked up in the soil. This may be of benefit in NVZs

Table 4.5

Industrial waste applied to land

Waste	Amount applied to land 1997 (max figure) wet tonnes
Waste wood, bark or other plant matter to agricultural land	1,000
Molasses	6,000
Dredging from inland waters	5,000
Septic tank sludges	9,000
Press sludge	16,000
Waste soil or compost to agricultural land	11,000
Waste lime	12,000
Waste soil or compost to non-agricultural land	21,000
Blood and gut contents from abattoirs	26,000
Paper waste (of which paper crumble is 46,000)	49,000
Sludges from biological treatment plant	52,000
Waste food, drink etc (of which distillery waste is 63,000)	76,000
Mixture of wastes	84,000
Estimated total	368,000

Source: SNIFFER, 1999[117]

Abattoir waste spread on farm land

where its application is being tested for its potential to reduce nitrate leaching. There are also concerns that biocides used in the paper making process could have an effect on soil micro-organisms. Pathogen content of industrial wastes is highly variable because of their diverse nature and their impact, persistence and risk to health of crops, animals and humans are largely unknown. Industrial wastes may also contain high levels of heavy metals, however unlike sewage sludge, there are no regulations to limit the build up of metals in soils from these sources. However, if a build up of metals poses a pollution threat then the exemption from Waste Management Licensing no longer applies and steps may be taken to modify inputs.

Distillery waste is one of the most common exempt wastes applied to agricultural land in Scotland. It is estimated that over 63,000 wet tonnes[120] are applied every year. Distillery waste is of concern because it can contain high levels of copper as well as other prescribed substances and current regulations do not control the build up of these substances in soil. SEPA is formulating a National Waste Protocol with distillers to manage the application of sludge to land for overall environmental benefit. Copper rich distillery sludge could be of benefit to copper deficient soils such as those identified in Speyside and other areas in NE Scotland[123].

Wastes are often applied to land 52 weeks a year, due to lack of storage facilities, so they could potentially be applied during inappropriate weather conditions. For example, during periods of heavy rainfall when soils are at field moisture capacity and when temperatures are low, there is limited plant growth and hence limited nutrient uptake. As a result, nutrients are likely to be leached from the soil, particularly if available in a soluble form.

4.1.3 Agricultural Wastes

Agricultural wastes, comprising manures, livestock slurries and silage effluent, are the most common types of organic waste applied to land in Scotland. Wastes generated and recycled on farms are not subject to statutory controls, although controls do exist over some practices such as storage.

It has been estimated[117] that 15 million tonnes of agricultural waste, mainly in liquid form, are recycled to land in Scotland each year. A further estimated 10 million tonnes are excreted directly on to the land by grazing animals[117].

Agricultural wastes may contain pathogens, but are generally not treated prior to application. Of particular concern is *E. Coli* 0157 since an above average incidence of the disease related to this pathogen is found in Scotland although the reason is not fully known. The survival and dispersal of *E. Coli* 0157 in water and soil is being investigated by SAC and through the Soil Health Initiative by MLURI and the University of Aberdeen. In addition, manures and slurries can contain high levels of heavy metals, particularly zinc and copper. Although the quantities of manures and slurries added to farmland are such that additions of pathogens and heavy metals can be considerable, their inputs are unregulated and, unlike some other European countries, there are no limits on stocking densities.

Some veterinary products and their metabolites can have environmental impacts when excreted by farm animals[19]. For example, the widely-used anti-parasitic drug, ivermectin, is persistent and residues in the faeces of treated livestock reduce the number and variety of dung beetles and insects, affecting in turn insect-eating birds and mammals. The impacts of sheep dip are discussed in **Chapter 3**.

Agricultural wastes are a significant source of nutrients which, ideally, should be appropriately balanced with inputs from other sources such as fertilisers and atmospheric deposition. However, there is no statutory requirement for manure management plans, other than in designated NVZs where inputs are limited to 170 kg N/ha/y. Soil eutrophication and saturation may result in leaching of nitrogen and phosphorus to surface and groundwaters.

Many agricultural wastes have very high BODs which can give rise to anaerobic conditions resulting in soil oxygen depletion and poor plant growth. Since 1982, the number of pollution incidents associated with run-off from animal wastes on farmland in Scotland has been growing[124] Recently commissioned studies are examining farm practices to determine what, if any, impact such practices have on the quality of Scotland's bathing waters.

4.1.4 Composted Waste

Very little compost is produced in Scotland, in contrast to several other European countries where legislation restricts the quantity of organic material that can be accepted by landfills. However, composting in the UK has been steadily increasing in response to changes in legislation and in anticipation of further incentives to diversify waste management and recycling[117]. The recently published *National Waste Strategy: Scotland*[125] envisages that composting will play an important role in reducing the amount of biodegradable waste going to landfill.

In 1994, composting of 14,000 tonnes of household waste was reported by 22 local authorities. Of the compost produced, 250 tonnes were sold to the public, 300 tonnes were used for public parks and the rest was sold to farmers and gardeners[126]. However very few applications for exemptions for use of composted waste have been made under the Waste Management Licensing Regulations 1994[120]. The addition of compost adds significant quantities of organic matter to soil which can result in lower levels of nutrients and heavy metals being available

Waste segregated for recycling and composting

for leaching to watercourses. The quality of the compost and the range of potential pollutants contained in it depends on the source of the organic waste.

SEPA's role

The application of organic wastes to land is principally controlled through The Sludge (Use in Agriculture) Regulations (1989) and the Waste Management Licensing Regulations (1994). SEPA's main role in the Sludge (Use in Agriculture) Regulations (1989) is in auditing the registers held by the sludge producers and water authorities and carrying out field inspections where applications have taken place. In the case of the Waste Management Licensing Regulations (1994) SEPA is the enforcing authority and must prove that the activities are being undertaken in accordance with the legislation. In addition, SEPA may take action under the Control of Pollution Act 1974 (as amended) in the event of pollution of controlled waters. The establishment of NVZs by SERAD limits the amount of nitrogen applied within the designated catchment. The application of organic wastes in these areas will be monitored.

Despite these regulatory controls, there are no limitations for nutrient additions, with the exception of designated NVZs, or organic contaminants following application of any type of organic waste and no limitations on heavy metal additions in wastes other than sewage sludges. The industrial wastes discussed above do not need a waste management licence, if their application results in benefit to agriculture or ecological improvement. However, these terms are not defined in legislation. No monitoring of soil quality indicators, such as pH or heavy metal concentration, is currently carried out on land to which the majority of organic waste is applied. However, SEPA intends to sample a range of potential contaminants in organic wastes and soils.

In 1998 SEPA completed a report *Strategic Review of Organic Waste Spread on Land*[120] which concluded that:

"the current approach to the regulation and management of organic waste spread on land is inadequate and inconsistent, leading to practices which pose a risk to the environment and have potential public, animal and plant health risks".

In relation to soil quality the report recognised that with the exception of sewage sludge the input of nutrients to land from organic wastes is not recorded and links are not made with inorganic fertiliser application. It also identified the lack of scientific knowledge about the pathogenic content of wastes, the fate of pathogens and organic contaminants in soil and the changes in soil processes brought about by the continued application of organic wastes. The report made a number of recommendations including:

- a consistent legislative framework for all organic wastes applied to land should be developed
- there should be a need to demonstrate beneficial recycling
- minimum standards of treatment should be set for all wastes
- blood and gut contents from abattoirs and septic tank sludges should not be applied to land.

The Scottish Executive recently responded to the report and is to bring forward amendments to the Waste Management Licensing Regulations. These will introduce a consistent legislative framework for all organic wastes spread to land and will require the demonstration of agricultural benefit or ecological improvement. In addition, the spreading of septic tank sludges to land will be banned. However, SEPA's recommendations in a number of key areas have not yet been taken forward. Specifically, the use of Land Management Plans on land where waste is applied, the certification of competence for spreading contractors and the banning of blood and gut content spreading, the decision on which has been deferred until the findings of the *E. Coli* Task Force are available in 2002. SEPA will continue to call for the implementation of all the recommendations made in the report.

The Sludge (Use in Agriculture) Regulations 1989 and the Waste Management Licensing Regulations 1994 are under review and the former will incorporate the Safe Sludge Matrix developed by ADAS, to eradicate risk of pathogen transfer to the human food chain. Although phased out under voluntary agreement in 1998, this will ban application of untreated sewage sludge to agricultural land and the application of treated sludge to the surface of grazed land. The revised regulations will define two levels of sludge treatment processes, 'treated' and 'enhanced treated' sludges. Enhanced treatment can virtually eliminate pathogens. It is expected that the revised regulations will be introduced during 2001. In addition, a proposed EC Sludge Directive will seek to lower the maximum permissible concentrations of heavy metals in soil and may set limits on concentrations of organic contaminants for the first time. It is likely that certain exempt wastes will be brought under a similar degree of control.

4.2 Landfill

The Issue

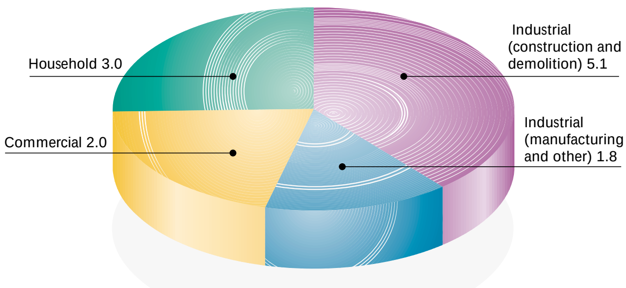
There are a range of environmental impacts associated with landfilling waste. Anaerobic decomposition of waste produces significant quantities of methane, a greenhouse gas and potential explosion hazard. The production of leachate can contaminate soil and pollute surface and groundwaters. In addition, landfilling can result in local odour and litter problems and importantly depletes natural resources.

State of the Environment

Landfill is the primary disposal mechanism for waste in Scotland. Over 90% of the waste produced is disposed of to landfill. In 1998 12 million tonnes of waste was landfilled, comprising 3 million tonnes of household waste, 2 million tonnes of commercial waste and 7 million tonnes of industrial waste (**Figure 4.1**). SEPA currently licenses 263 landfill sites in Scotland. The location of the sites and the type and tonnage of wastes accepted are shown in **Figure 4.2**.

Figure 4.1

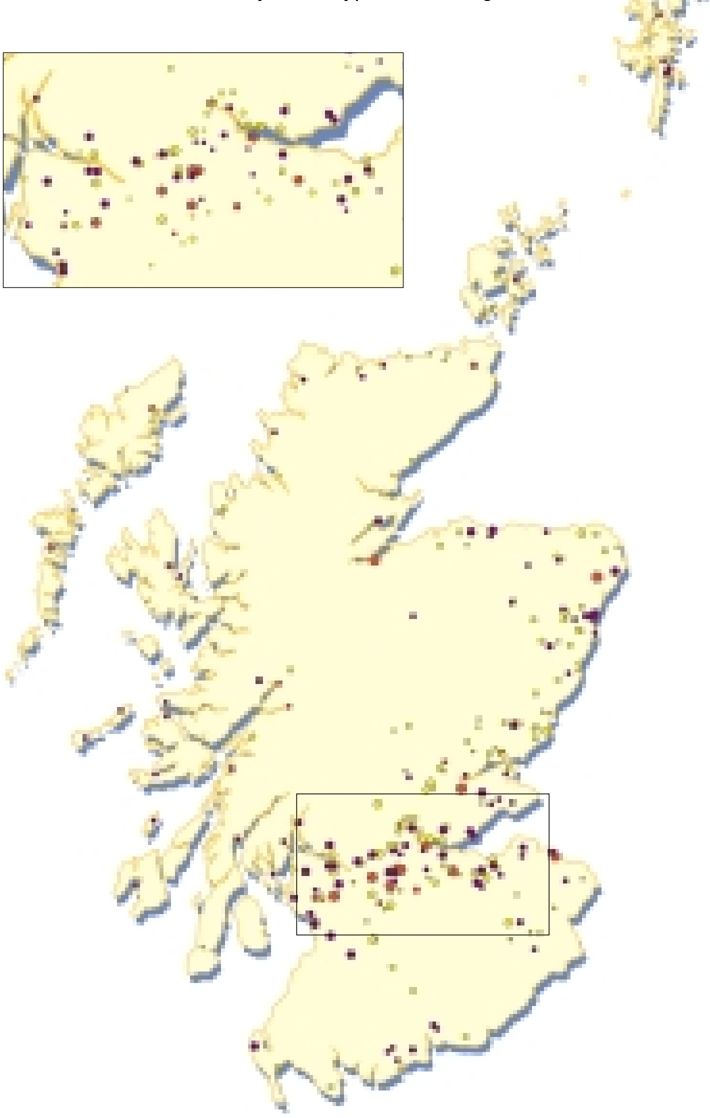
Disposal to landfill in 1998 (million tonnes)



Source: SEPA, 1999[125]

Figure 4.2

Licensed landfill sites by waste type and tonnage



Landfill sites licensed to accept the following types of waste: (thousand tonnes per annum)

Household, commercial or industrial waste

- 0 - 25
- 25 - 75
- 75 - 150

Inert waste

- 0 - 5
- 5 - 25
- 25 - 75
- 75+

Household, commercial or industrial waste including specific hazardous waste

- 0 - 25
- 25 - 75
- 75 - 150
- 150+

Source: SEPA, 1999[125]

An important impact of landfill on soil quality is from the production of leachate, a liquid which may contain a wide array of pathogens and chemical pollutants. In the past, landfilling was based on the principle of dilute and disperse and very little or no control was placed on leachate generation and leakage. The extent of soil contamination arising from seepage of leachate from landfill sites is unknown. Leachate can significantly alter soil characteristics as it moves through the soil. RCEP[19] concluded that there is likely to be a zone approximately 100 to 200 metres wide downhill from landfill sites where leachate causes the soil to be anaerobic and it is thought that most degradable compounds in landfill leachate will be broken down in this zone[127].

Leachate is contained within modern landfills by impermeable membranes and may be treated on site, tankered to sewage treatment works, recirculated through the landfill or sprayed onto nearby land, including forestry. At present only two landfill sites apply leachate to land; one in Perthshire onto a small area, less than 0.4 hectares of conifer forest and one in Galloway onto deep peat over an area of about 2 hectares. This practice is licensed under the Waste Management Licensing Regulations (1994) and an assessment of soil and hydrogeology must be made prior to application for the protection of controlled waters. There is little information on the effects of landfill leachate on soil processes, but where leachate has been used for irrigation negative effects have been demonstrated on microbial activity, including nitrogen-fixing activity[128,129].

SEPA's role

SEPA grants licenses to landfill sites with the aim of reducing the impact of pollutants on the environment. The EC Directive on Landfill of Waste which came into force in 1999 set targets to reduce the amount and environmental impact of wastes to landfill. The main targets include a reduction in the amount of biodegradable municipal waste going to landfill by 25% by 2006 and by 65% by 2016 relative to a 1995 baseline. SEPA has recently published the *National Waste Strategy: Scotland* which sets out a national approach to developing a sustainable integrated waste management system. In addition, the new Pollution and Prevention and Control (Scotland) Regulations will introduce additional environmental controls that SEPA may apply to some landfill sites.

5. Summary

The main pressures on land from industry, agriculture and forestry and waste application to land are summarised below. All have an impact on soil quality, however, there are significant gaps in knowledge about the inputs, concentrations and fate of pollutants in soil. For example, inputs of heavy metals and POPs, whether through atmospheric deposition or inputs from industrial waste application are not monitored. Generally, impacts on soil quality and long term effects on soil sustainability are not well understood. Impacts on soil quality and subsequent effects on the wider environment are summarised in **Table 5.1**.

5.1 Pressures from Industry

- The area of derelict and vacant land has fallen in recent years, from 13,721 hectares in 1995 to 11,982 hectares in 1999. It is, however, still being created at a rate of nearly 700 ha per year.
- The extent of land which is chemically and radioactively contaminated is not yet known accurately, although there are examples of a range of contaminants around industrial plants.
- Elevated rates of atmospheric sulphur and nitrogen deposition affect most of the land. Acidification of soil associated with this deposition exceeds the soil's capacity to assimilate it in 55.5% of the land area, or 85.6% if ammonia deposition is included.
- Rates of atmospheric deposition and resultant accumulation of heavy metals and POPs in soil are largely unknown. Deposition rates in Scotland are estimated to be at the low end of values found across Europe. There is, however, some evidence of their accumulation in soils.
- Due to global climate change Scotland's climate is predicted to become warmer by between 1.2 and 2.6°C and wetter, with annual precipitation increasing by between 5 and 20%.

5.2 Pressures from Agriculture and Forestry

- Soil erosion has been recorded both on lowland arable land and in the uplands. The extent of erosion on agricultural land is not quantified. In the uplands, the most severely eroded areas are in the Monadhliath Mountains, the eastern Southern Uplands and the eastern Grampians.
- Inorganic fertiliser application to arable and grassland averaged 122 kg/ha and 49 kg/ha in 1996 for nitrogen and phosphorus respectively. For the UK as a whole, amounts have decreased since a peak in the mid 1980s.
- Pesticide use totalled 7,767 tonnes (active ingredients), applied over 500,000 hectares of cereal crops, potatoes and oilseed rape. Nearly 80% was sulphuric acid applied to potato crops as a desiccant. In addition, over 2 million litres of waste sheep dip chemicals were disposed of to land in 1999.
- Agriculture, including land use change and forestry, is a large sectoral source of greenhouse gases in Scotland contributing 36% of total emissions of which soil is a major contributor.
- Agriculture is the largest source of atmospheric ammonia in the UK. Deposition rates across Scotland range from less than 6 to over 14 kg N/ha/y. The largest deposition rates occur in Aberdeenshire and south-west Scotland.
- Forests cover approximately 16% of the land area of Scotland and can have both beneficial and detrimental environmental impacts, depending on management practices.

Industry in Grangemouth

Table 5.1

Potential impacts of Industry, Agriculture and Forestry and Waste Application to Land on soil quality and the wider environment

Pressure	Impact on soil quality	Impact on wider environment
Industry		
Abandonment of land	loss of soil resource	loss of greenfield land and biodiversity, increased reliance on transport
Chemical contamination	potential loss of ecosystem function	pollution of water resources, impact on human health and plant growth
Radioactive contamination	unknown	transfer from soil to food chain leading to potential impacts on human health
Acid deposition	modified rates of nutrient cycling and decomposition rates leading to leaching of base cations and heavy metals, organic matter accumulation	eutrophication and acidification of water resources, leaching of elements toxic to aquatic life, negative impacts on plant and tree health.
Climate change	changes in rates of nutrient cycling, enhanced decomposition rates, potential deterioration of soil physical structure	increased atmospheric concentration of radiately active gases, vegetation change, impact on agricultural production
Agriculture and Forestry		
Management practices	soil erosion, loss of organic matter, deterioration of physical structure	pollution of surface waters through eutrophication and sedimentation, loss of agricultural productivity, loss of vegetation
Fertiliser use	soil eutrophication and acidification, soil microbial processes affected, potential deterioration of physical structure	eutrophication of surface waters, leaching to groundwaters and potential impacts on human health, elevated emission of nitrous oxide, vegetation change
Pesticide use	soil microbial processes and biodiversity potentially affected	pollution of water resources, transfer to human foodchain and potential impacts on human health, impacts on non-target organisms, loss of biodiversity
Greenhouse gases	soil can act as source and sink	climate change
Ammonia emission and deposition	soil eutrophication and acidification leading to modified rates of nutrient cycling and decomposition rates	vegetation change, eutrophication of water resources
Afforestation	changes in organic matter type and accumulation with subsequent impacts on nutrient cycling and decomposition rates, acidification.	eutrophication and acidification of surface waters, potential for carbon sequestration
Waste Application to Land		
Heavy metals	negative impacts on soil microbial biomass, processes and diversity	pollution of water resources, uptake into crops and human foodchain
Organic compounds	largely unknown, potential impacts on microbial diversity	evaporation to atmosphere, uptake into crops and food chain, impacts on human and animal health
Pathogens	unknown	uptake into food chain, impacts on human health, pollution of water resources
Landfill	loss of soil resource, impacts of leachate on soil microbial properties	pollution of water resources, source of methane

5.3 Pressures from Waste Application to Land

- Approximately 185,000 wet tonnes of sewage sludge were applied to just over 4000 ha of agricultural land in 1996-1997. This amount is expected to rise to 858,000 wet tonnes by 2005-2006.
- Approximately 368,000 wet tonnes of industrial wastes were applied to agricultural land in 1998. The most common were distillery waste, blood and gut content from abattoirs and paper waste.
- Approximately 15,000,000 tonnes of agricultural wastes, mainly comprising manures, livestock slurries and silage effluent, are applied to agricultural land each year.
- Organic wastes contain variable quantities of heavy metals although only the heavy metal content of sewage sludge is monitored and regulated.
- Organic wastes contain a range of organic compounds such as benzene and phthalates. Inputs to soil are not monitored or regulated.
- Organic wastes also contain pathogens. Their nature and inputs to soil are not monitored or regulated.
- There are 263 licensed landfill sites in Scotland. Modern landfills treat leachate prior to disposal and only two sites apply leachate to land as a disposal mechanism. The extent of soil contamination from old landfill sites is unknown.

5.4 Regulatory Framework

Soil protection has not been specifically addressed by current environmental protection legislation. Some legislation requires SEPA to protect the environment as a whole, and some refers to aspects of soil protection specifically, but soil protection is generally not viewed as a priority issue. However, this view is changing and the importance of soil protection is increasingly being recognised. In 1996 RCEP[19] recommended that a soil protection policy be drawn up and implemented for the UK. The UK Government's intention to produce a national strategy for soil protection was described in its response in 1997 to RCEP's recommendation. A Soil Strategy for England has recently been published for public consultation[132].

Forthcoming regulations have the potential to improve soil quality and SEPA will seek to integrate and raise the priority of soil protection within existing legislation. SEPA will formulate its own internal soil strategy and will consider soil protection when setting emission limits on prescribed substances from industrial processes over which it has control. SEPA will also seek to include the issue of soil quality and sustainability when developing and implementing policy and will formulate internal guidance to its staff on soils issues to be considered when issuing licences. SEPA's current and future roles in soil protection are summarised below.

Mixed agriculture at Corrieshalloch Gorge near Ullapool

Industry

SEPA regulates discharges from large industrial sources principally through Integrated Pollution Control (IPC), the main objective of which is to protect and enhance the environment as a whole, and other regulations, such as Air Pollution Control (APC). Soil protection is rarely considered and the accumulation of prescribed substances in soils is not monitored. Several new and forthcoming pieces of legislation will result in an improvement in soil quality. For example, statutory contaminated land will have to be remediated under Part IIA of the Environmental Protection Act. The recently introduced PPC (Scotland) Regulations 2000 consider installations as a whole rather than focusing on individual processes. It will require sites, when operations cease, to be returned to a pre-operational state and will encompass installations such as intensive pig and poultry units from which the atmospheric emission of ammonia will be a particular focus. In addition, several EC Directives, such as the National Emissions Ceilings Directive, are being aimed at reducing emissions of acidifying compounds, heavy metals and organics from industry.

Ploughing

Agriculture and Forestry

SEPA's regulatory activities with respect to agriculture are limited to protecting the water environment. SEPA's main influence is through promoting the PEPFAA Code[82], farm and waste management plans and other educational activities. However, Regulations such as the Protection of Water Against Agricultural Nitrate Pollution (Scotland) (1996) should result in an improvement in soil quality. The EC Water Framework Directive has the potential to benefit soil quality, based as it is on river basin management and considering the role soil management has in preventing pollution of the aquatic environment. In contrast, the disposal of waste agrochemicals to land under the Groundwater Regulations (1998) could potentially damage soil quality. The use of Integrated Crop Management and the growth in organic agriculture should benefit soil quality. In addition, SEPA has recommended that CAP reform should link agricultural subsidies to compliance with the PEPFAA Code and that funding for agri-environment schemes be substantially increased.

Waste Application to Land

Spreading slurry

SEPA controls some application of wastes to land through the Sludge (Use in Agriculture) Regulations (1989) and the Waste Management Licensing Regulations (1994). Soil protection is considered in setting standards for maximum concentrations of heavy metals. Spreading other organic wastes is exempt from licensing. SEPA has recommended to the Scottish Executive that a consistent legislative framework for the application of all organic wastes to land be developed. The Sludge (Use in Agriculture) Regulations (1989) and the Waste Management Licensing Regulations (1994) are currently under review. It is anticipated that sludges will have to be treated prior to land application. In addition, a proposed EC Sludge Directive will lower the maximum permissible concentrations of heavy metals in soil and may set limits for the first time on concentrations of organic contaminants in soils to which sludges are applied. It is likely that certain exempt wastes will be brought under a similar degree of control to that afforded sewage sludge. The EC Directive on Landfill of Waste and SEPA's recently published *National Waste Strategy: Scotland* aims to reduce the amount and environmental impact of wastes to landfill.

European Context

At present there is no overall soil protection policy across the European Union. Several EU countries have soil protection policies and associated monitoring strategies. Germany has had a Soil Protection Plan since 1985 and a more recently introduced Soil Protection Act which is an umbrella for implementing soil policy elements which are regulated within other Federal Laws. In Denmark a main aim of soil protection is to prevent contamination of groundwater which is the main source of drinking water. A central principle of the Dutch Soil Protection Act is protecting soils' multifunctionality from human activities.

The European Soil Charter adopted in 1972 recognised the soil deterioration occurring in many parts of Europe and recommended that soil be protected from a range of pressures including urban development, pollution and erosion. In a recent report[133] the European Environment Agency and the United Nations Environment Programme identified that Europes soil resource is being lost and degraded at an unprecedented rate and identified an urgent need for a European soil monitoring and assessment framework. They recommended the integration of soil assessment approaches and soil protection policies. The forthcoming EU's 6th Environment Action Plan includes the protection of soils from pollution and erosion as an objective and proposes a thematic strategy for soil protection.

Research needs

Soil is a relatively poorly understood habitat and research is required in many areas as summarised below.

- soil quality definitions relevant to the wide range of land uses and soil types.
- soil parameters or indicators to monitor the quality of soil.
- relationships between microbial biodiversity and ecosystem function.
- impacts of the pollutants discussed above on soil processes and ecosystem function.
- rate of recovery of soils from the impact of the pollutants discussed above.
- interaction between natural and human pressures contributing to soil erosion.
- role of land management in mitigating of greenhouse gas emissions.
- impacts of fertilisers and pesticides on long-term soil fertility.

SEPA has sponsored a range of research projects on soil quality issues through SNIFFER. These include developing a biological risk classification scheme for heavy metals in soils, a guidance manual and protocol for assessing potential adverse effects of substances in soil on designated terrestrial ecosystems, a review of ecological and biological tests for the assessment of contaminated land and assessment methodology for radioactively contaminated land. SNIFFER has been exploring the possibility of a soil quality research theme in 2001. SEPA also has some influence on the research programmes of the EA, NERC and SERAD and is represented on the steering committees of NERC's Soil Biodiversity Programme, Countryside Survey 2000 and the UK Climate Impacts Programme.

6. Conclusions and Recommendations

This report describes the main pressures and impacts on soil quality from human activities. There is evidence to suggest that all the pressures identified are affecting soil quality to a greater or lesser extent. SEPA believes that the principal threats to soil quality and the long-term sustainable use of soils come from:

- Agricultural practices, in particular those that lead to soil erosion and loss of soil fertility. The emission of greenhouse gases is also an issue.
- Acid deposition, as a result of the sensitivity of many Scottish soils and their expected long recovery time.
- Application of organic wastes to land, from which the input of contaminants and their likely impact is largely unknown.

To protect soils from future unsustainable land use practices and pollution, SEPA believes a soil protection strategy should be developed and implemented.

Such a strategy should:

- ensure soil is recognised as a non-renewable resource essential to the maintenance of a sustainable environment
- ensure pollutant inputs to soil and land use practices do not irreversibly affect soil quality
- ensure soil protection is taken into account at all levels of environmental decision making
- ensure current soil use is consistent with the aims of sustainable development
- protect the multifunctional role of soils
- ensure the ability of a soil to act as a buffer and transformer of pollutants is managed sustainably
- identify areas at risk of irreversible change and take precautionary measures
- establish a framework for a soil monitoring programme

Knowledge relating to the sustainable use of soil is scarce and major gaps relating to trends in pollutant inputs to soil and resulting impacts on the quality and therefore sustainability of soil are identified. Because of this lack of information relating to changes in soil properties over time, it is not possible, at this stage, to assess whether current land use practices and pollutant inputs are sustainable. For these reasons, SEPA believes a quantitative assessment of the soil resource is required as an initial step in the implementation of a soil monitoring programme. Long term monitoring of soil quality is essential in order to assess whether the current status is sustainable and to assess whether potential soil protection measures are successful.

As a first step in addressing these issues SEPA has formulated a number of key recommendations and outlined its own role as described below.

SEPA recommends:

- a Soil Protection Strategy for Scotland should be formulated in partnership with relevant bodies
- a quantitative assessment of the Scottish soil resource should be undertaken
- a long-term soil monitoring strategy should be developed and implemented
- existing legislation relevant to soil protection should be integrated

SEPA will:

- participate actively with other partners in developing a soil protection strategy
- formulate its own internal soil strategy
- develop protocols to ensure the protection of soil quality from emissions from SEPA regulated activities, particularly when consenting discharges to land and air
- continue to support and influence soil quality research
- seek to ensure that the wider environmental benefits of soil protection are recognised in the framing of forthcoming legislation
- continue to encourage application of Codes of Good Practice relevant to soil protection

Information Requirements

There are many areas where information is required, particularly regarding the input, persistence and bioavailability of potential contaminants as well as their impacts on soil quality and sustainability. Areas where information is required are described below.

Industry

There is a clear need for the inputs of pollutants to soils to be monitored, both around industrial areas and in areas remote from sources. In addition, a systematic survey of the bioavailability and accumulation of potential contaminants is required. Information is also required on their persistence and effects they may have on key soil processes such as nutrient cycling and decomposition of organic matter.

Agriculture and Forestry

To assess the long-term sustainability of agriculture, it is crucial that accurate information on the soil resource, such as levels of organic matter, nutrient status and pH, is collected at regular intervals. Long-term effects of fertiliser and pesticide use on soil quality need to be assessed. There is a need for a systematic examination of soil erosion along with the quantification of erosion rates. The role of land management in the maintenance of soil quality and alleviation of many environmental problems, such as diffuse pollution, needs to be assessed. Such management will have an important role to play in minimising physical damage and loss of soil, minimising the impacts of soil acidification and eutrophication, conserving current carbon stocks and minimising future emissions of greenhouse gases from soils.

Waste Application to Land

Inputs of organic wastes to soils, with the exception of sewage sludge, are largely unregulated and impacts on soil quality and sustainability are unknown. Information needs to be gathered on the inputs and accumulation of the potential contaminants present in organic wastes, such as heavy metals, organic compounds and pathogens, and impacts on soil quality. Information is also required on the concentration and persistence of contaminants around landfill sites.

Farmland and the Lomond Hills near Kinross

Although SEPA's statutory role in soil protection is limited, the targets outlined below have been set within specific regulatory functions.

SEPA will regulate to:

- ensure 100% compliance with statutory requirements concerning soil contamination under The Sludge (Use in Agriculture) Regulations 1989
- monitor soil contamination arising from the disposal of industrial wastes to land in 20% of sites by 2005
- fulfill responsibilities for contaminated land under Part IIA of the Environmental Protection Act
- ensure that disposals of prescribed substances onto land, under the Groundwater Regulations, do not adversely affect soil quality
- reduce the area showing eutrophication near intensive agriculture installations under Pollution Prevention and Control Regulations

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Glossary

Adsorption	A process where molecules of a substance are taken up and held on the surface of a material.
Aerobic	Describes a process that requires oxygen.
Anaerobic	Describes a process that does not require oxygen.
Anthropogenic	Describes effects produced by human activities.
Bioavailability	The extent to which a substance is available in a form that can be taken up by plants and animals
Biogeochemical cycling	The paths followed by the essential chemical elements in living organisms, from the environment to the organisms and back to the environment.
Buffering capacity	The capacity of a material to oppose changes in chemical properties, for example when acid or alkali is added.
Carbon sequestration	the uptake and storage of carbon by, for example, trees and peat bogs.
Critical load	The threshold for deposition of a pollutant below which significant harmful effects do not occur.
Diffuse pollution	Pollution from sources which cannot be traced to a single point source, such as deposition from the atmosphere.
Eutrophication	Nutrient enrichment of water or soil.
Greenhouse effect	A warming effect where solar radiation enters the atmosphere but once reflected from the earth is absorbed.
Greenhouse gases	Gases in the atmosphere that contribute to the greenhouse effect, including carbon dioxide, methane, nitrous oxides, ozone, chlorofluorocarbons (CFCs) and water vapour.
Heavy metal	A group of metals with a density greater than 6g/cm^3 that may be toxic to living things when present in concentrations above normal background levels. Examples include lead, mercury, and zinc.
Improved grassland	Grassland which has been subject to management practices, such as fertiliser application, which results in a change in species composition and diversity.
Lipophilic	Attracted to fatty substances.
Microbial biodiversity	The diversity of micro-organisms ie bacteria, microscopic fungi, algae and protozoa.
pH	The measure of the degree of acidity or alkalinity of a solution based on its concentration of hydrogen ions.
Persistant Organic Pollutant	An organic chemical which has a long residence time in the environment.
Point source pollution	Pollution from single sources such as a sewer or pipe discharge.
Radioisotope	Radioactive isotope of a stable element.
Rough grazing	Grazing land which has not been subjected to management techniques such as liming or fertilisation, to improve the quality of the grazing.
Semi-natural vegetation	Vegetation which exists in a near-natural state under minimum management.
Spatial heterogeneity	Diverse nature of a property over an area.
Sustainable development	Development that meets the social, economic and environmental needs of the present generation without compromising the needs of future generations.

Units

kg/ha/y	Kilogram per hectare per year
mg/km^2/y	Milligram per sqaure kilometre per year
mg/kg	Milligram per kilogram
µ/kg	Microgram per kilogram
t	Tonnes
m/km^2	Metres per square kilometre
ha	Hectare
t/ha	Tonnes per hectare
kt/y	Kilotonnes per year
Tg/y	10^{12} grammes per year
keq/ha	kilo-equivalents per hectare

Acronyms

APC	Air Pollution Control
BPEO	Best Practicable Environmental Option
BSSS	British Society of Soil Science
CEH	Centre for Ecology and Hydrology
COMAH	Control of Major Accident Hazard
CAP	Common Agricultural Policy
CLAG	Critical Loads Advisory Group
DETR	Department of the Environment, Transport and the Regions
EC	European Commission
EU	European Union
EEA	European Environment Agency
EA	Environment Agency
ICM	Integrated Crop Management
ICRCL	Interdepartmental Committee on the Redevelopment of Contaminated Land
IPC	Integrated Pollution Control
IPCC	Intergovermental Panel on Climate Change
ITE	Institute of Terrestrial Ecology
LEAF	Linking Environment and Farming
MAFF	Ministry of Agriculture, Fisheries and Food
MLURI	Macaulay Land Use Research Institute
NEGTAP	National Expert Group on Transboundary Air Pollution
NERC	Natural Environment Research Council
NVZ	Nitrate Vulnerable Zone
PAH	Polynuclear Aromatic Hydrocarbon
PCB	Polychlorinated Biphenyl
PCDD	Dioxin
PCDF	Furan
POP	Persistent Organic Pollutant
PPC	Pollution Prevention and Control
RCEP	Royal Commission on Environmental Pollution
SAC	Scottish Agricultural College
SAC	Special Area for Conservation
SEPA	Scottish Environment Protection Agency
SERAD	Scottish Executive Rural Affairs Department
SNH	Scottish Natural Heritage
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
SVDLS	Scottish Vacant and Derelict Land Survey
TEQ	Toxic Equivalent
UKROFS	UK Registered Organic Food Standards
UNECE	United Nations Economic Commission Europe

Useful Web Addresses

AEA Technology	www.aeat.co.uk
BSSS	www.bsss.bangor.ac.uk
DETR	www.environment.detr.gov.uk
EA	www.environment-agency.gov.uk/
EEA	www.eea.eu.int/
EMEP	www.nilu.no/projects/ccc/
IPCC	www.ipcc.ch/
MAFF	www.maff.gov.uk
MLURI	www.mluri.sari.ac.uk
NEGTAP	www.nbu.ac.uk/negtap/
NERC	www.nerc.ac.uk
SEPA	www.sepa.org.uk
Scottish Executive	www.scotland.gov.uk
SNH	www.snh.org.uk
Soil Association	www.soilassociation.org/SA/SAWeb.nsf

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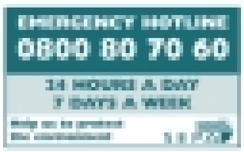

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