ENVIRONMENTAL
Standards Scotland
Ìrean Àrainneachdail na h-Alba

The risks to Scotland's soils: a scoping report

October 2024

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Key findings, recommendations and further work

The importance of soil to Scotland's environment

Key finding 1: Soils provide a wide range of services for the environment, ecosystems and human activity. They are one of the most diverse and important habitats on earth and underpin the production of the vast majority of Scotland's food. Healthy soils regulate key biogeochemical cycles, including nitrogen and carbon cycles and so can limit both the causes and impacts of climate change (for example, by capturing greenhouse gases and reducing flooding and vulnerability to drought).

Key finding 2: Degradation of soil has an economic impact. In Scotland, erosion, compaction and reduced crop yield caused by lower water retention cost the economy up to £125 million per year – the true cost of degradation is likely to be significantly higher but there is insufficient data for many of the risks to soils to determine costs associated with them. For every 1% increase in flooding associated with soil degradation there will be an increase in local authority flood damage costs of £2.6 million per year in addition to insurance claims of up to £75,000 per property for a single flood event.

Legislation

Key finding 3: The legislative landscape for soils is particularly fragmentary and there is no framework legislation to protect soils equivalent to the Water Environment and Water Services (Scotland) Act 2003 and the Air Quality (Scotland) Regulations 2000 which seek to protect our water and air. The legislative landscape for soil largely aims to protect other elements of the natural environment (such as water) from poor management of soils, rather than soil itself.

Key finding 4: The Scottish Soils Framework was published by Scottish Government in 2009 but, unlike soil frameworks in other countries, was not developed with the intention of enacted it into law. The main aim of the framework was to promote sustainable management and protection of soils. The framework identified 'soil outcomes' and the actions required to achieve them, including proposing the introduction of a soil monitoring action plan. Only a small number of tasks in the action plan have been implemented and there is currently no systematic nationwide monitoring scheme in Scotland.

Key finding 5: In addition to the European Union's (EU's) proposed Nature Restoration Law, which includes requirements for setting a satisfactory level for soil carbon stocks and targets for the restoration of peatland soils, proposals for a Directive on Soil Monitoring and Resilience are also at an advanced stage. Scottish Government, formerly a world leader with the Soils Framework, is falling behind international best practice in this area and will need to consider mirroring developments in Europe if Scotland is to keep pace. The proposal for a Directive on Soil Monitoring and Resilience includes practices which would lead to improvements in Scottish soil and adopting these will be beneficial to Scotland's environment.

Key finding 6: Other countries have legislated to place monitoring and protection of soils on a statutory footing. One of the best examples of this is Switzerland, which developed a soil strategy then quickly enacted this into law in 2020. Findings of the Swiss Soil Monitoring Network (NABO) must be reported to policy makers every five years.

Recommendation 1: Under its commitment to keep pace with EU law, the Scottish Government should bring forward legislative proposals that reflect the proposed EU Soil Monitoring Law and Nature Restoration Law by introducing a statutory duty to protect and monitor soil, creating mandatory targets for restoration of drained peatland soils and reassessing contaminated land and soil sealing policy. The legislation could build upon the work undertaken in 2009 and recent work on monitoring by the Joint Nature Conservation Committee and James Hutton Institute.

Risks to Scotland's soil

Key finding 7: Environmental Standards Scotland (ESS) has identified 12 risks to soil in Scotland, several of which also pose a risk to the wider environment. ESS has undertaken a preliminary analysis of these risks to inform decisions about which should be prioritised for further scrutiny or analysis, or where action is required by the Scottish Government and others to address them. The risks ESS has identified and discussed in this report are summarised in the list below:

- from application of waste to land
- from biodiversity loss
- from carbon sequestration schemes
- from compaction
- from contamination
- from the approach to data and monitoring
- from disease and pests
- from erosion
- from landfilling waste soil
- to soil carbon
- from soil sealing
- to and from water retention, flooding and drought

Key finding 8: Compaction, erosion and the loss of soil organic matter (including soil organic carbon) are closely linked risks to soil quality. These in turn can reduce the water storage capacity and thus increase the risk of flooding and decrease the resilience to drought. They pose a risk to crop yields, biodiversity, climate change reduction, flooding and water supplies and quality. Soil carbon stocks appear steady in Scotland, but compaction and erosion rates in Scotland are higher than in EU countries and the United Kingdom (UK). Water levels stored in Scottish soils are also predicted to drop due to climate change.

Further work by ESS: ESS will undertake further analysis of the impact of compaction and erosion on soil services in Scotland. This will involve a comprehensive review of: all issues linked to compaction and erosion; water retention and drought resistance including soil carbon (specifically soil organic matter, as it relates to compaction and erosion, but not the sequestration of atmospheric carbon); and the effectiveness of existing policy and legislative approaches to managing them.

Key finding 9: Contaminated land is regulated by Part 2A of the Environmental Protection Act 1990. This requires local authorities to identify and investigate potentially contaminated sites. Some local authorities have stated they are not doing this routinely. The majority of contaminated sites are instead handled through the planning system.

Further work by ESS: ESS has begun investigatory work on the effectiveness of, and compliance with, Part 2A of the Environmental Protection Act (1990). In particular, ESS will consider whether local authorities across Scotland are routinely carrying out their duties under Part 2A and whether failures to identify contaminated sites may pose environmental risks.

Key finding 10: There is a lack of research in Scotland on several risks to soil. Areas ESS has identified as particularly lacking are: soil biodiversity; soil and water contamination caused by spreading of waste on land (such as sewage sludge); and the impact of carbon sequestration schemes on soil carbon stocks (such as tree planting). As a consequence, there is insufficient data for ESS to draw conclusions on the level of risk associated with these issues.

Recommendation 2: Improving the evidence base on soil will improve the effectiveness of environmental law in Scotland. ESS recommends that Scottish Government and the wider public sector (e.g. NatureScot, SEPA and Scottish Forestry amongst others) commission monitoring and research to address identified gaps in the evidence base. This should be supported by data gathered from a nationwide monitoring programme introduced by legislation to keep pace with the EU's proposed Soil Monitoring Law.

Key finding 11: The loss of soil to landfill poses several risks to the services provided by soil and the wider environment but detailed analysis of the data and evidence available on the drivers for, and disincentives to, this practice in Scotland is beyond the scope of this report. ESS will continue to monitor data relating to the landfilling of hazardous and non-hazardous soil waste and will undertake further scrutiny if appropriate.

Key finding 12: Soils are a vector for diseases and pests that pose risks to plants, crops and to national food security. ESS is satisfied that sufficient work is being done by public authorities in relation to soilborne diseases and pests and no further work by ESS in this area is proposed.

Glossary

Anaerobic digestate – the residual material left after the anaerobic digestion process, where bacteria break down organic matter in the absence of oxygen. It can be used as a fertiliser.

Carbon dioxide equivalent (CO_2e) – the number of metric tonnes of CO_2 emissions with the same global warming potential as one metric ton of another greenhouse gas.

Carbon sequestration – the process of transferring carbon from the atmosphere (e.g. as CO_2), through plants and other organisms, which is then retained in the soil as soil organic carbon resulting in a global carbon stock increase of the soil.

Carbon stocks – the amount of carbon stored in soil in an area.

Erosion – where soil particles become detached from the surface and are transported within the landscape by water or wind.

Eutrophication – the accumulation of nutrients in water leading to the growth of algae.

Fertility – the capability of a soil to support plant growth.

Infiltration rate – the speed at which water percolates through soil.

Less favoured areas (LFAs) – designation of farmland where production conditions are difficult due to, for example, poor soil, climate or terrain.

Land capability for agriculture classification – a system which scores land use capability upon a series of guidelines. The official agricultural classification system in Scotland.

Mycorrhizae – a symbiotic relationship between fungi and plants.

Peat – soils comprised of decomposed or partially decomposed organic matter.

Peat soil – soil with an organic layer at the surface over 50cm deep (also referred to as an organic soil).

Peatland – land with peat soil or peaty soil types present and with peat-forming vegetation growing and actively forming peat, or has grown and formed peat in the past.

Remediation – the treatment of soils to remove contaminants.

Run-off – water flowing over the surface of soil or a sealed area.

Soil biodiversity – the variety of life in soils.

Soil health – the biological, chemical and physical condition of soils and their ability to sustain the productivity, diversity and environmental services of ecosystems.

Soil nutrients – compounds and elements in soil which help plant growth including nitrogen, phosphorus and potassium.

Sewage sludge – the residue left after wastewater treatment.

Soil organic carbon – the carbon component of organic matter in soil.

Soil organic matter – all living, or once-living, materials within, or added to, the soil.

Soil quality – the capacity of a soil to function i.e. to sustain biological productivity, maintain environmental quality and promote plant and animal health. Also used as an agricultural definition of soil health, which considers the condition of the soil in relation to agricultural production.

Soil sealing – the process of covering soil with impermeable surfaces, such as roads, concrete and buildings.

Soil structure – the arrangement of solids (soil mineral and organic particles) and pore spaces within the soil.

Water retention – the ability of a soil to store water.

1. About this report

1.1 This report considers the risks posed to soil in Scotland. It also considers the risks that soils and the way that humans interact with them pose to the wider environment. This is a scoping report, aimed at determining what risks to Scotland's soils exist, identifying relevant legislation, and briefly researching and summarising the risks in order to identify and prioritise those which require further attention by ESS or others. A scoping report is used by ESS as an initial assessment to understand and agree on the nature and scope of the problem in context before carrying out further work. In this context, the report also focuses on the national level rather than the local.

1.2 ESS' strategic plan identified a number of analytical priorities.[1] ESS identified that developing a better understanding of the current status of soil health, controls and monitoring was a priority for analysis because of:

- soil's importance to other aspects of the environment and society such as agriculture, forestry, climate change, biodiversity and water quality
- the lack of data currently available to assess the status of Scotland's soil health
- the proposals for new legislation governing soils from the European Union – the Nature Restoration Law and the proposed Directive of the European Parliament and of the Council on Soil Monitoring and Resilience[2,3]

1.3 Section 20 of the UK Withdrawal from the European Union (Continuity) (Scotland) Act 2021 ('the 2021 Act') sets out the scope of ESS' functions. ESS' remit is to:

- ensure public authorities, including the Scottish Government, public bodies and local authorities, comply with environmental law
- monitor and take action to improve the effectiveness of environmental law and its implementation

1.4 ESS has prepared this report as part of its remit to assess compliance with environmental law, and the effectiveness of environmental law or how it is implemented and applied, with the aim of developing an understanding of the risks posed to soil in Scotland to determine if any immediate action is needed to protect soils and if there are any risks which require further research. Section 20 of the 2021 Act enables ESS to make recommendations to public authorities. ESS may also identify specific concerns that merit further investigation, or topics that will be prioritised for future analysis or ongoing monitoring.

1.5 There is a particular focus on legislation as the medium for regulation in this report. ESS' role includes monitoring EU environmental law and identifying areas where Scottish Government needs to act to maintain its commitment to keep pace with EU law. As the EU is in the final stages of negotiations for the proposed Soil Monitoring Law, this report focuses on legislation as the primary method for regulating soil health. The EU Soil Monitoring Law states that "A legislative rather than a non-legislative approach is needed to meet the long-term objective of healthy soil in the EU by 2050." [2]

1.6 This report:

- summarises the scoping work carried out by ESS to identify what risks soils in Scotland face, and what risks to the wider environment unhealthy soils pose
- identifies existing legislation and policies relating to soil in Scotland and any potential gaps
- summarises how ESS has prioritised where further work is required and where ESS can add most value
- outlines the conclusions that ESS has reached, including issues where ESS considers that action by Scottish Government and others is necessary and issues where ESS proposes to undertake further analysis or investigation

1.7 ESS' findings and recommendations are based on:

- evidence gathered from a review of published academic literature and government documents
- information provided by, and discussions with, organisations with an interest in soil in Scotland and the wider UK

1.8 ESS asks the Scottish Government, in coordination with its agencies, to make a statement, as soon as possible and within six months of publication of this report, setting out their response to the recommendations made to them in this report and the action they intend to take to address them.

1.9 ESS will discuss the findings in this report with the public authorities concerned to explore their potential response to the recommendations and to inform ESS' future assessment of progress on these, and related, issues.

1.10 The findings and recommendations in this report will be kept under review and ESS will consider, in due course, whether further analysis or investigation into the issues identified is required. Where appropriate, this analysis will also inform future work on other analytical priorities, for example, on climate change adaptation and mitigation.

1.11 Nothing in this report, or the recommendations made within it, limits ESS' ability to make decisions about further scrutiny of the issues covered, for example, in response to representations made to ESS on related matters.

2. The importance of soils to Scotland's environment

2.1 Soil is a complex system made of different proportions of minerals, organic material, air, water and life. Soils are often considered because of how important they are for other aspects of the environment, such as climate and water, but they are an important environment in their own right and a non-renewable resource. Soils represent one of our most diverse ecosystems, with more than half of species on Earth living in soil at some point in their lives.[4] Soils also provide the basis of production for 95% of our food.[5]

2.2 Soils provides a wide range of services to other environments and life living above them. The wealth of biodiversity that lives in soil provides food for animals that live above ground, including declining wildlife like many species of birds and bats.[6] Soils have the potential to limit the impact of climate change in several ways. This includes storing carbon and limiting the impacts of droughts and flooding.[7,8]

2.3 Many soil properties are closely linked – organisms and organic carbon in soil help improve its structure, meaning soils are at a lower risk of compaction. Soils that have been compacted are at a greater risk of erosion, which results in carbon loss. Compacted soils have a lower ability to retain water, which increases flooding and further increases erosion and decreases biodiversity and drought resistance. A loss of biodiversity can exacerbate the loss of drought resistance further as some soil bacteria can help plants tolerate drought.

2.4 Degradation of soil has a negative impact on Scotland's economy. Currently, soil erosion and compaction costs in the region of £75 million per year, in addition to a loss of between £16 million and £49 million per year due to reduced crop yield caused by a loss of water retention. The true cost of degradation is likely to be significantly higher, but there is insufficient data for many of the risks to soils to apportion costs associated with them. This is in addition to the cost of flood damage caused by soils with lower water retention capacity.[9]

2.5 There are several recognised classifications of soils in use in Scotland. The primary one is the Scottish Soil Classification (updated in 2013), which was developed by the national soil survey and recognised thirteen soil classes. The most common soils type in Scotland are: gley soils (poorly drained soils, 20.6% of land area); podzols (acidic soils, 23.7%); brown earths (moderately acidic, well drained); and peat soils (soils which are made up almost entirely of organic matter, 22.5%).[10,11] The focus of this report is on non-peat soils, although peat soils are discussed where they are particularly relevant.

2.6 According to the 2023 Agricultural Census, around 70% of Scottish land is agricultural.[12] Soil underpins agriculture by providing nutrients, water and a growing medium for crops and grass. Maintaining or increasing the fertility of soils contributes to food security and profitability for farmers by providing stable or higher yields of crops and feed.[2]

2.7 Soil is key to determining what type of farming can take place. Healthy, high-quality soils can support a wide range of crops, including biofuel crops and woodlands. These soils allow successful arable agriculture to take place and tend to be present in land categorised as prime agricultural land (classes 1 to 3.1 in the Land Capability for Agriculture (Scotland) classification). This land is most common on the east coast, around Fife, East Lothian, Tayside, around the Moray, Cromarty and Dornoch Firths and Aberdeenshire.[13] Around 7% of Scotland fits into this category compared to 17% in England's equivalent classification (ALC grade 1 to 3a).[14,15] A map showing the capability of land for agriculture in Scotland is included in Figure 2-1.

2.8 Compared to prime agricultural land, a much higher amount of agricultural land in Scotland is in a 'less favoured area' (LFA) and capable of supporting only mixed agriculture, improved grassland or rough grazing (LCA classes 4-7, and some LFA land may be in class 3.2). LFAs are areas where farming is made difficult due to poor soil, climate or terrain. In England, 17% of farmland is classified as LFA – in Scotland LFAs make up 85% of farmland.[16,12] With so little prime agricultural land, it is crucial for Scotland to maximise the health of its agricultural soils to maintain food security.

2.9 Soils are also vital in the fight against climate change. Soils provide a stable repository for carbon (over 3000 megatonnes [Mt])[17] and can sequester new carbon which would otherwise be in the atmosphere.[18] In Scotland, the measured uptake of carbon by land accounts for up to 10Mt of carbon dioxide equivalent (CO2e) per year – roughly equivalent to the annual emissions of greenhouse gases from Scottish agriculture, although the majority of uptake is in forested areas rather than farmland.[17] However, the Climate Change Committee has identified that soils is one of eight priority policy gaps for Scotland.[19]

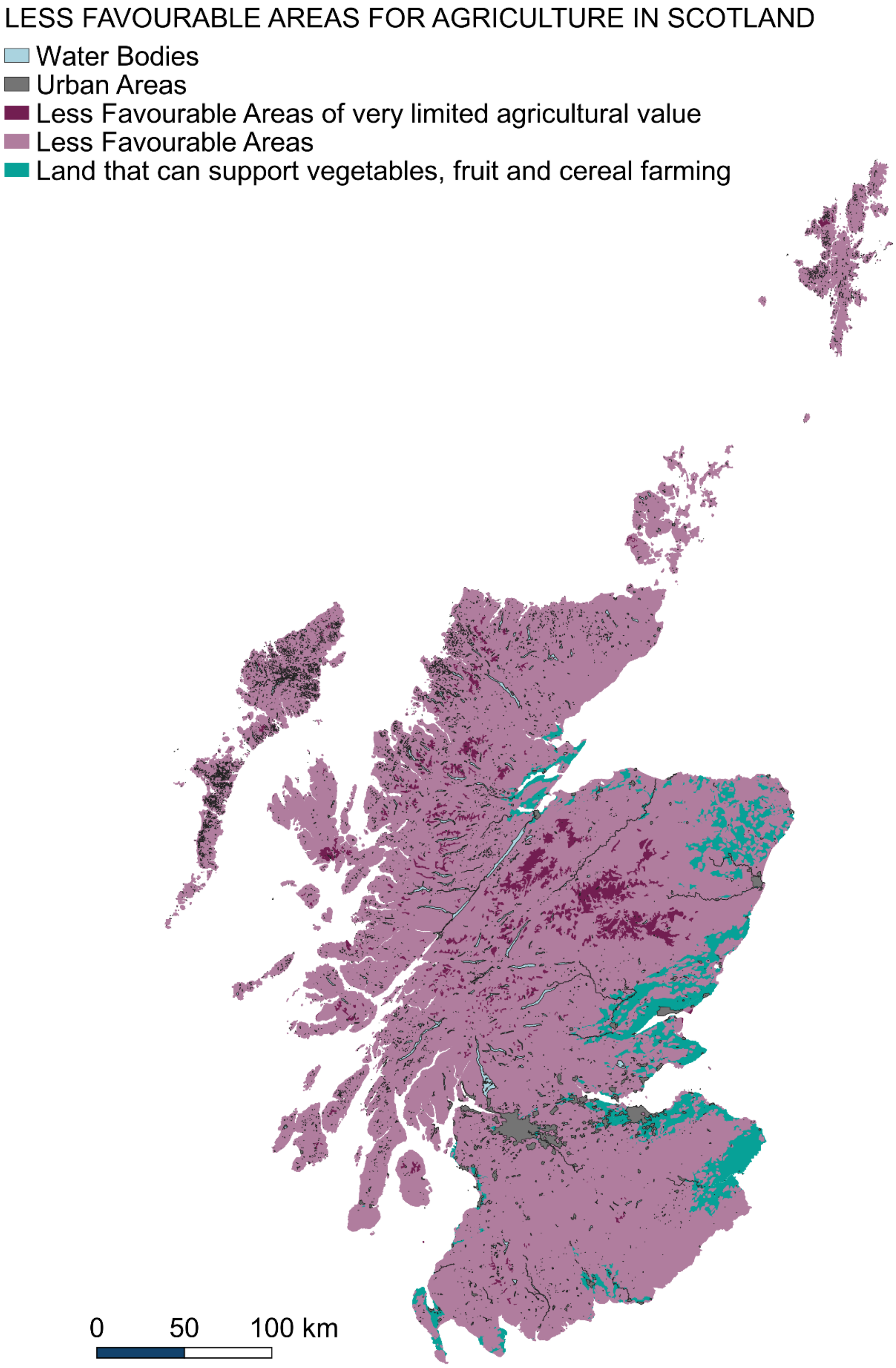


Figure 2-1: Agricultural land capability in Scotland

2.10 The Scottish Climate Change Plan encourages improving soil management to use soils as a carbon store. The focus of the actions in the plan is on peatland. Peatland soils are particularly important for the mitigation of climate change, storing more than half of soil carbon in Scotland.[17] The plan includes a target to restore 250,000ha of degraded peatland by 2030.[20] Fertilised agricultural soils are also a key source of the potent greenhouse gas nitrous oxide.

2.11 As well as mitigating climate change by reducing greenhouse gas levels, soils can also limit the negative impact of climate change events. Where soils are in good structural condition and with good biodiversity, the infiltration rate of water into the ground and the water-holding capacity of soil is higher.[21] This in turn reduces flooding risk by reducing the amount and rate of surface water run-off into water bodies.[7] A sampling study found that 18% of topsoils and 9% of subsoils in fields tested in Scotland are in a state of severe structural degradation.[22] If soils are less resistant to drought, then crop yields and drinking water reserves will go down.[23]

2.12 On a cultural level, soils protect archaeology from damage. As much of the archaeological record remains undiscovered, the European Commission’s Joint Research Centre states that soils that preserve cultural heritage should be regarded as valuable.[20]

2.13 Despite the importance of soils as a resource, roughly a quarter of the 2.4 million tonnes of material disposed of in landfills in Scotland in 2022 was soil.[24] Most of this comes from construction projects. Furthermore, new development seals soils beneath buildings, roads and concrete. In Scotland, 2% of soils are sealed compared to 2.3% across the EU.[25,26] Sealing soils or disposing of them in landfill reduces the amount of soil available for carbon sequestration and to retain water, and soil sealing means that most other soil functions are lost and the risk of flooding is increased.[27] Soil sealing predominantly takes place in urban areas and so the impacts of the effects it causes, particularly flooding, are felt most, economically, environmentally and socially.

2.14 Soil can become contaminated when exposed to excessive pollutant load from industrial activity, agriculture, waste disposal and leaks and spills of raw materials and fuels. The contamination can travel through several routes, posing a risk to the wider environment through direct contact with soil, migration through surface and groundwater and as gases, dust and vapour impacting air quality. Historic contamination is particularly prevalent due to a lack of knowledge of environmental hazards and poor practice in the past.[28]

2.15 In high enough concentrations, contamination in soil can cause significant harm to human and animal health, property or wider biodiversity, and cause significant harm to surface and ground water.[29] There is also an association between areas of deprivation and contamination land in Scotland.[30] While soil can be contaminated, it also acts as a filter for pollutants. This allows soil to protect surface and groundwater from contamination, including excess nutrients and pesticides.[31]

2.16 Soils are an environment that supports life within and above it that is threatened in several ways. Some of these threats in turn provide threaten other parts of the environment. Across the EU, 60-70% of soils are in an unhealthy state.[32] As a result, it is important to monitor soils to know whether soil health, fertility and quality, and its ability to provide services like climate change mitigation and flood resistance, are improving or declining.

2.17 The right measures for protecting soil can be underpinned by reviewing monitoring data and seeing if changes have led to improvements or degradation. Soil monitoring data can then be used to determine how successful climate change mitigation measures have been, as well as changes to ensure food security and drought resistance and flood prevention. To ensure its usefulness, monitoring data must be harmonised and consistent to make sure data can be compared easily over time.[2] Monitoring should also be clearly aligned with targets to ensure that they are being met or worked towards. These reasons are given by the EU as the basis for the proposed Soil Monitoring Law.

2.18 Because soil is being degraded by a range of human activities, natural processes and climate change, ESS has considered soils from the perspective of the risks posed to it and subsequently the wider environment. The work considers all soils, including urban and agricultural soils used by humans, but also natural and semi-natural soils although peat soils are only considered where they are particularly relevant.

2.19 An overview of the risks to Scotland's soils identified in this report is shown below in Figure 2-2.

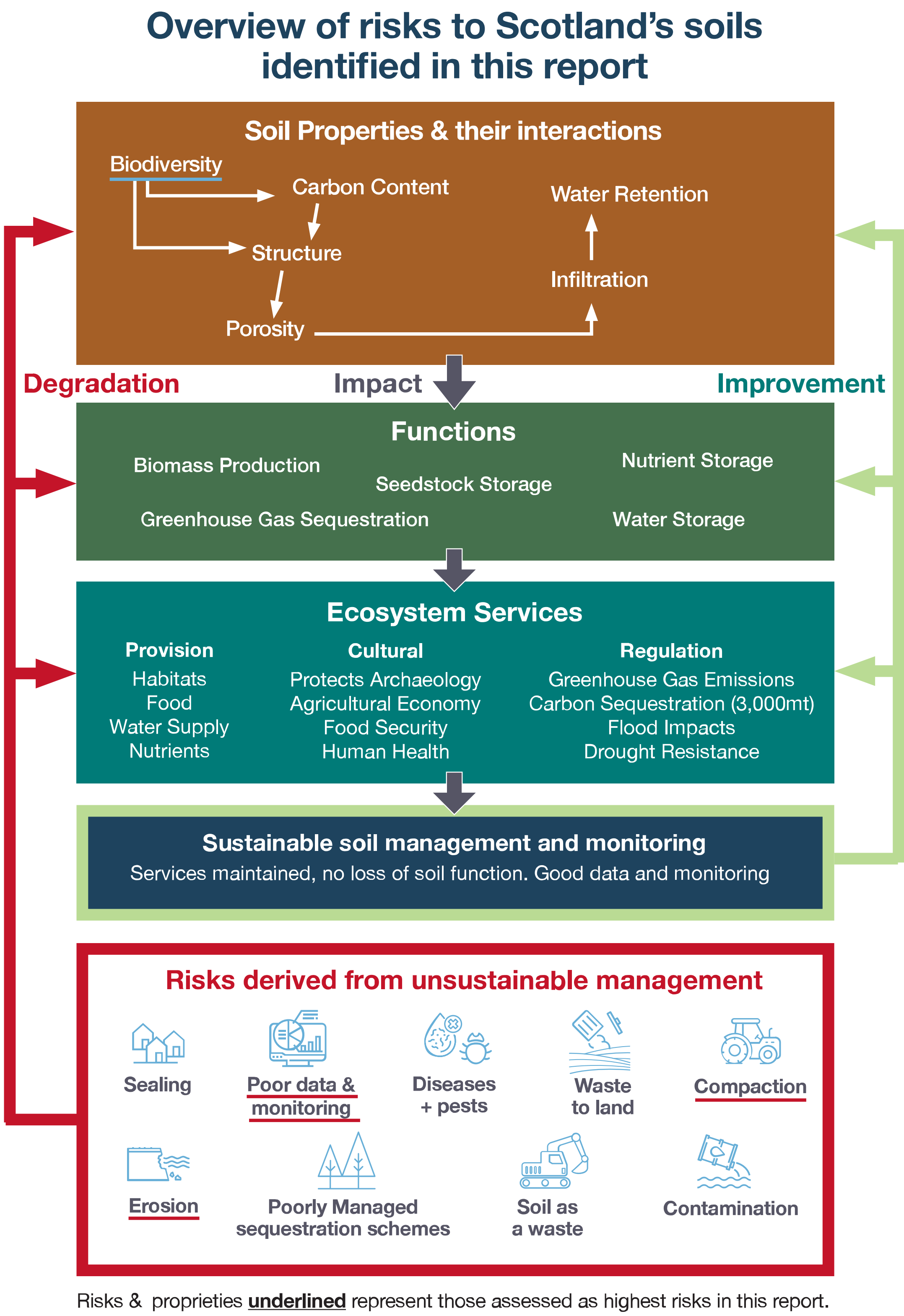


Figure 2-2: Overview of risks to Scotland's soils identified in this report

3. Existing policy and legislative landscape

3.1 Soil is mentioned in over 2,000 pieces of UK legislation. However, there is no overarching soil law in Scotland or the UK, and currently none in the EU. Instead, soil is included in legislation relating to agriculture, contamination, climate change, water, waste and land use, among others. A summary of the policies and legislation relating to soil is included in Annex 2.

3.2 Scotland does have a Soil Framework, published in 2009, but this has not been enacted into law. The Scottish Government's report on the framework stated that the policies at the time did "not cover all soils and all threats to soils, and so do not constitute a coherent soil protection strategy". The report identified numerous pressures on soils, but no legislative changes were recommended as a result of its publication. The outcomes of the Scottish Soil Framework were not time limited, but the actions stipulated by it were and were due to be reviewed five years after the publication of the framework. This review took place in 2013, but no further reviews have taken place.

3.3 As a result of this fragmentary legislative landscape, only some aspects of soil are protected by law. What legislation exists tends to focus on a specific impact or property of soil. Legislation also often protects soil indirectly, with the primary aim being the protection of another aspect of the environment.

3.4 An example of this is the Water Environment (Controlled Activities) (Scotland) Regulations 2011. These control when and how activities which impact the water environment can be carried out. This includes the use of fertiliser on soils. This has the indirect effect of protecting soils from the application of excess fertiliser, but this is not the primary intention of the regulations. The aim is to protect the water environment from excess nutrients leaching or running off soil into surface or groundwater.

3.5 The only country in Europe with a single overarching piece of legislation on soil currently is Switzerland, although Germany and Austria also have policies which vary by region. The Swiss National Soil Strategy began as a framework, which was then implemented into policy and legislation within a year.[33] The Swiss Strategy has six overarching objectives: to reduce soil consumption (loss of soil under artificial land cover); manage soil consumption; protect soil from harmful impacts; restore degraded soils; improve awareness of the value and sensitivity of soil; and strengthen international commitment to soil protection.

3.6 The strategy commits to soil consumption in Switzerland being reduced to zero by 2050 – soils may still be built on, but must be offset elsewhere. Similarly, loss of soil function due to construction must be offset elsewhere. The Strategy includes a legally mandated soil monitoring network (NABO) and a commitment for an area of arable land, based on the area needed to feed the country in a crisis, to be protected. Payments for farmers are also linked to soil health and crop rotation.[34]

3.7 The EU has proposed a Directive on Soil Monitoring and Resilience (Soil Monitoring Law), referred to from here on as the Soil Monitoring Law. The directive aims to improve soil health across the EU and aspires to have all soils in a healthy condition by 2050, although this is not a legally binding target. The law requires member states to monitor soil health by analysing for a range of indicators. Some of these indicators have threshold values set at EU level, while some will be set at member state level, above which action should be taken.

3.8 The law also defines a methodology for sampling, the identification and investigation of contaminated land and defines and sets out rules for sustainable soil management. These rules are generally in accordance with the World Soil Charter's definition of sustainable soil management:

> "Soil management is sustainable if the supporting, provisioning, regulating, and cultural services provided by soil are maintained or enhanced without significantly impairing either the soil functions that enable those services or biodiversity. The balance between the supporting and provisioning services for plant production and the regulating services the soil provides for water quality and availability and for atmospheric greenhouse gas composition is a particular concern."

3.9 While the proposed Soil Monitoring Law does not set out how to protect soils and ensure the indicators stay within the thresholds, it provides a single piece of legislation defining which aspects of soils should be monitored to encourage their improvement, although member states may choose to implement it through multiple pieces of legislation.

3.10 The EU's intention is to have all soils in a healthy condition by 2050. This is essential to meet net zero and nature positive climate resilient goals. As part of this, monitoring will allow the health of soils to be assessed. Once the monitoring data has been reviewed and any trends in soil health determined, appropriate measures to protect soils can then be taken. The EU propose that the data collected by the monitoring regime will be used to help select suitable technological, management practices and organisational solutions to manage soil. Monitoring data will also be used to help monitor trends in droughts, water retention and erosion which will support disaster prevention in relation to flooding, water scarcity and landslides.[35]

3.11 The importance of monitoring frameworks has been identified in other aspects of the environment. Monitoring of air quality and water is carried out regularly. The monitoring data is used to ensure environmental targets are met. The Sustainable Soils Alliance reported that between 2017 and 2018, the Environment Agency in England spent £60.5 million on water monitoring and, together with local authorities, £7.65 million on air quality monitoring, but only £283,780 was spent on soil monitoring by the Department for Environment, Food and Rural Affairs (DEFRA) and Natural England.[36] By contrast, Northern Ireland is now spending £37 million on the soil nutrient health scheme over a four-year period.

3.12 By producing a soil monitoring framework, the EU will collect soil monitoring data that uses the same sampling and testing methods and indicators of soil health throughout the area and over time. This allows data from different places and sampling dates to be compared to determine trends and help identify reasons for changes in soil health. If different tests are used between monitoring regimes, they are difficult to compare, and if monitoring is not repeated at regular intervals, trends in soil health will not be observed.

3.13 The EU adopted the Nature Restoration Law in June 2024. The law includes a requirement to monitor organic carbon content in cropland mineral soils. While peat is not the main focus of this report, the Nature Restoration Law also sets mandatory targets for the restoration of "organic soils in agricultural use constituting drained peatlands". The law requires states to put in place measures which aim to restore soils and the measures should be in place on at least 30% of these areas by 2030, 50% by 2040 and 70% by 2050.

3.14 Outside Europe, the United States (US) introduced legislation to protect soil as far back as the 1930s (Soil Conservation Act 1935). This introduced the department now known as the Natural Resources Conservation Service (NRCS), which was set up during the 'Dust Bowl'. The Dust Bowl was a series of dust storms caused by drought, poor farming methods destroying topsoil and wind eroding soils. Soil erosion was identified as a threat to the ability of the land to sustain agricultural productivity and the rural communities that depend on it for their livelihoods. The NRCS provides funding and technical assistance to farmers and foresters to improve soil health as well as planting vegetation to reduce erosion.[37]

3.15 While Scotland developed a Soils Framework, it is not legally binding. Other countries such as Switzerland and the US have introduced soil legislation which legally protect soils at a national level. The EU is in the process of introducing new legislation which will require mandatory monitoring of soils with the aim of observing trends and eventually protecting degrading soils. With the introduction of the Soils Framework Scotland was once world leading, but is now falling behind international best practice.

4. The risks to Scotland's soils

Risk identification process

4.1 Soils are not a static entity and are continuously evolving in response to changes in natural soil forming factors (time, climate, geology, landform and biota) and how land is managed. However, soils and the services that they provide are at risk from excessive pressures from human activity and climate change. ESS set out to identify these risks to soils and the risks that degraded soils pose to the wider environment and cultural heritage.

4.2 To ensure that as many of the risks were identified as possible, a review of relevant government and academic literature was carried out. The review was sense-checked by engaging with a range of regulators, organisations and businesses with an interest in soil. To minimise the inherent risk of bias in the analysis, care was taken to speak to a wide range of stakeholders with business, environment, government and NGO perspectives. Stakeholders were interviewed using the same set of questions. A full list of stakeholders that ESS contacted is included in Annex 1.

4.3 At the end of this stage of the process, ESS identified a range of risks to soil health and to the services provided by soil. These risks have been placed into the following broad categories for review by determining which soil property was the driver for the risk, or which human activity was the driver for the risk from or to soil health:

• from application of waste to land • from biodiversity loss • from carbon sequestration schemes • from compaction	• from contamination • from the approach to data and monitoring • from disease and pests • from erosion	• from landfilling waste soil • to soil carbon • from soil sealing • to and from water retention, flooding and drought

4.4 These risks were arrived at through stakeholder engagement and are not exhaustive. The categories were assessed individually to determine the nature and scale of the issue in Scotland and the impact the issue is having. There are several detailed datasets on soils in Scotland. However, at this stage a review of major datasets including the findings of the National Soil Inventory for Scotland (NSIS), BioSOIL and LUCAS (the EU JRC's Land Use and Coverage Area frame Survey) has not been carried out due to the high-level nature of this scoping and framing report. These and other large datasets may be reviewed in the future, as part of more detailed work that is commissioned as a result of this report.

Risk prioritisation process

4.5 Following analysis, the twelve risks to soil health, soil services and the wider environment were prioritised using a set of prioritisation criteria that mirrored those used in ESS' Strategic Plan.[1] The risks were scored high, medium or low based on: the severity and likelihood of the impact (indicating risk magnitude); the nature and scope of the issue; neglect of the issue in policy; the value that ESS can add by looking at a topic; a comparison with other countries; and ESS' level of confidence in the evidence available and knowledge of each topic at this stage. All criteria used the same scoring system and were not weighted based on their importance. There is an element of judgement in the application of the scores, but the method presented is repeatable and proportionate for a scoping exercise.

4.6 Each score level was assigned a number reflecting the severity of impact and assessment of level of certainty in ESS' knowledge (1 for the lowest severity or highest confidence, to 3 for highest severity and lowest confidence). An overall risk category (high, medium or low) was then determined from the total scores. A matrix showing the risk assessment scores and the detailed criteria used to determine the scores is included in Annex 3.

4.7 Detailed information and evidence relating to each risk is presented in the following sections, beginning with risks associated with key indicators of: soil health (compaction [section 4.8]; erosion [section 4.18]; water retention [section 4.28]; soil carbon [section 4.35]; biodiversity [section 4.44]; and pests and diseases [section 4.50]). This is followed by the risks associated with waste management, development and the built environment: (contamination [section 4.56]; soil sealing [section 4.67]; landfilling waste soil [section 4.75]; application of waste [section 4.83]; and carbon sequestration schemes [section 4.90]), noting that these activities will adversely affect the core indicators of soil health. Finally, information and evidence relating to the risk from Scotland's approach to data and monitoring is presented (section 4.94). For each risk, a brief overview of the issue is provided, alongside the associated pressures, current status in Scotland and other European nations and relevant legislation. ESS' score is then set out for each risk, with our intended next steps.

Risks from compaction

4.8 Soil compaction results in a breakdown of soil structure and is caused when excessive force is applied to soil. It was identified as one of the main threats in the State of Scotland's Soils Report.[8] Compaction costs Scottish farmers over £25 million in crop losses and additional fuel use, and this could rise to over £70 million as compaction worsens.[9]

4.9 Compaction results in a change in the organisation of pores in the soil (reduction in size, loss of connectivity), which can impede free movement of liquid and air throughout the soil profile and increases its bulk density, impacting soil function and soil services. Compaction can result in reduced biodiversity, water infiltration and drought resistance. It can also lead to increased erosion, waterlogging, nitrous oxide emissions and flooding.[38,39,40] This can include localised surface water flooding (flooding on land) and an increase in the impact of fluvial flooding (flooding from rivers) downstream.[41]

4.10 Compaction also reduces oxygen levels and impedes nutrient flows in the soil which restricts root establishment and crop growth.[38] Compaction threatens food security as it can lead to drops in crop yields.[42] Land management practices that increase biodiversity and soil carbon can help reduce the risk of compaction. Reduced compaction also leads to reduced erosion and reduces carbon emissions from soils. [38,39,40,43]

4.11 Soil compaction is caused by farm machinery, livestock, construction, overgrazing by deer and recreational activities.[38,8] Heavy machinery and agricultural activity are considered the main causes of subsoil compaction.[38] However, compaction from non-regenerative agriculture is difficult to avoid during long wet spells, and the increasing demand for food from a growing population and market pressures have driven farmers to increase machinery size and livestock densities and work in poor weather conditions for soil.[40,8] Increasing weather volatility due to climate change is also leading to work being carried out in poor weather.

4.12 The power, and therefore weight, of farm machinery used in Europe has increased since the 1950s with wheel loads increasing from under 2 tonnes to around 9 tonnes.[44,45] Increased machinery weight transmits stresses deeper into the soil profile. A study in Denmark found that wheel loads over 3-4 tonnes are likely to cause persistent compaction in subsoil.[8] The increase in machinery weight has led to increases in compaction and drops in crop yields. As machinery size has increased, tyre-soil contact area of the machines has increased at a slower rate. This means that there has been an overall increase of the average stress at areas of contact between tyres and soil.[44]

4.13 The lack of a systematic national survey of soil means that there is insufficient data on soil compaction, from either direct measurements or from proxies like bulk density, in Scotland for ESS to make a full assessment of the state of compaction as part of this scoping and framing report. As a result, this report and previous studies have not been able to provide a quantitative assessment of the extent of soil compaction at a national scale.

4.14 The lack of data also makes it difficult to predict future trends in compaction associated with climate change and increased rainfall.[38] The NSIS (2007-2009) found that approximately one third of soils sampled in eastern and central Scotland had an air filled porosity value of less than 0.1 $m^3 m^{-3}$ which is considered to restrict root growth.[38] In Europe, 25% of soils are significantly compacted and in the UK 22% of sample sites were classified as severely or highly degraded in 2004, based (in part) on compaction status.[46,47] A 2015 survey of a selected number of Scottish farmers carried out by Scotland's Rural College (SRUC) found that 70% of their grassland fields had poor or moderate soil structure.[48]

4.15 There is no legislation in Scotland to regulate compaction, although the National Planning Framework 4 (NPF4) does require that development is carried out in a manner that protects soil from compaction and erosion.[49] Under the replacement for Common Agricultural Policy (CAP), the Good Agriculture and Environmental

Conditions (GAEC) 5 requires Scottish farmers to minimise soil erosion. Farmers are required to meet these rules to receive full payments under certain schemes and there are also penalties for non-compliance. The guidance does give some stipulations for compaction, but only where it causes increased erosion. The guidance recommends cultivating post-harvest land and late harvested crops using primary cultivation methods such as ploughing.[50]

4.16 The proposed EU Soil Monitoring Law requires member states to monitor subsoil compaction using bulk density in subsoil, or an equivalent parameter. Topsoil compaction must also be monitored, but no criteria are provided, and member states are not required to set any. Subsoil compaction is to be monitored in all non-natural environments, which would include construction sites as well as farmland.[2]

4.17 Scotland's Centre of Expertise for Waters (CREW) published a report assessing the socio-economic impacts of soil degradation in 2024. This recommended that a national field-based assessment of the extent of topsoil and subsoil compaction is carried out, as required by the proposed EU Soil Monitoring Law. The report also recommended that further research is carried out in relation to compaction and climate, that flood risk mapping and modelling is linked to estimates of additional run-off from compacted soils and that a framework is developed to combine the impacts and costs of compaction and erosion.[9]

Risk assessment – High: The severity of the impact of compaction and erosion on soil services is considered high and is impacting the ability of soil to absorb and store water. There is a lack of legislation relating to these risks and they all appear to be getting worse. Compaction, erosion, water retention and soil carbon content are all closely linked so ESS proposes to combine these topics for more detailed analysis in a further analytical project which will start in 2024. This will be an in-depth analytical project which will review these specific topic areas in greater detail and may make any recommendations required to reduce these risks.

Risks from erosion

4.18 Erosion of soil is a naturally occurring process. However, soil erosion on inappropriately managed land occurs at elevated levels, which can lead to negative impacts on soil health, soil services and the wider environment. This includes soil and nutrient run off into water bodies which causes pollution, loss of nutrient rich topsoil and a reduction in crop productivity. Erosion may also impact biodiversity by moving seeds and displacing soil fauna and can spread disease vectors across fields.[38] The proposed EU Soil Monitoring Law recognises that airborne soil particles produced by wind erosion also cause or worsen respiratory and cardiovascular diseases.[2]

4.19 Erosion of agricultural soils is estimated to cost the Scottish economy around £49.5 million per year, including costs for drinking water treatment.[51] In Scotland, soil erosion by surface water run-off (rather than wind) is the dominant process. Vulnerability to soil erosion increases where soil organic matter content is reduced, due to poor soil structure and extreme rainfall and is linked to agricultural practices such as tillage.[38,38] Soil erosion risk is also linked to compaction, particularly on agricultural and forestry land and construction sites. Water cannot infiltrate compacted soils and instead moves over the surface, taking soil with it.[38]

4.20 Observed erosion rates in Scotland in arable areas range from 0.01 tonnes per hectare per year (t ha-1 yr-1) to 23.0 t ha-1 yr-1, compared to a tolerable limit of 1.0 t ha-1 yr-1.[51] However, the lack of a comprehensive monitoring network in Scotland, means that it is not known whether the number of incidences and magnitude of erosion is increasing or decreasing.

4.21 Based on the findings of a literature review carried out by Cranfield University and the Hutton Institute, the average soil loss from arable and improved grass agricultural land in Scotland is between 1 and 10 t ha^{-1} yr^{-1}.[51] Erosion rates reported from 2010 for the EU and UK combined as a whole averaged 2.22 -2.46 t ha^{-1} yr^{-1} of soil lost from agricultural land, forests and semi-natural areas in erosion prone land through water erosion for all areas and erosion prone land respectively.[52]

4.22 The cost of erosion to the Scottish economy is significant and is linked to several other risks identified in this report. In agricultural systems, dealing with the consequences of erosion (gully formation, soil displacement, embankment instability) creates recurrent annual costs to farmers. Tillage and other land preparation will ‘restore’ the soil to remove erosion features that occurs during a growing season. In 2019, erosion in Scotland was estimated to cost £49.5 million per year due to increased treatment of drinking water, declines in yields, additional fertiliser and greenhouse gas emissions.[51] This is in addition to the costs to wildlife and fisheries.

4.23 Soil erosion is one of the most significant risks to the conservation of archaeological sites.[53] Archaeological evidence at or near the surface can be damaged by machinery which erodes and compacts soil. While compacted soil may help preserve archaeology by limiting water infiltration and root penetration, compacted soils are more prone to erosion. Only one study on the impact of soil condition on archaeology in Scotland has been identified.[54] The study found that agriculture (in particular ploughing) and erosion has caused significant damage to archaeology.[54]

4.24 The risks to archaeology should be considered during Environmental Impact Assessments (EIAs) carried out before certain agricultural work and development projects. ESS has reached an informal resolution with the Rural Payments and Inspections Division (RPID) on the implementation of agricultural environmental impact assessments regulations that should help reduce risks in this area by enforcing the requirement for assessments to be produced before carrying out certain agricultural practices.[55]

4.25 There is a good understanding of the processes initiating soil erosion and available mapping of risk of erosion in Scotland, but there is no systematic nationwide survey of erosion in Scotland. The lack of a consistent monitoring regime makes it difficult to monitor trends or the scale of the problem of erosion.

4.26 As with compaction, there is no legislation in Scotland to regulate erosion, although the NPF4 does require that development is carried out in a manner that protects soil from erosion.[49] Under CAP, GAEC requirements included mandatory soil protection measures against erosion including limiting bare soils, promoting reduced tillage, the increased use of grass margins and maintaining stone walls. The available evidence implies that GAEC has led to a 9.5% reduction in soil loss rates, with a reduction of over 30% in the UK, one of the highest falls in the EU.[52]

4.27 The proposed EU Soil Monitoring Law includes soil erosion rate as one of the mandatory health indicators, with a criterion of <2 t ha-1 yr-1 set at Union level.[2] The criteria are being regularly exceeded across Scotland.[51,52] The EU proposal recognised that the criterion does not apply to badland (dry areas of eroded sedimentary rocks and clay) and other unmanaged natural land with inherent high risk of erosion. This is likely the case in many Scottish Highland areas, where the exceedance is due to the presence of highly organic soils and/or peat and natural processes associated with mountainous areas.[51,52]

Risk assessment – High: As erosion is linked to other important aspects of soil health and poses a risk to food security, flooding and reduced drought resistance the risk is considered high. There is no legislation relating to erosion. ESS proposes to consider erosion in conjunction with compaction, soil carbon content and water retention in the proposed analytical project detailed in the previous section.

Risks from and to water retention, drought resistance and flooding

4.28 Soil moisture content is linked to a range of processes including drainage, run off, infiltration and plant growth. Soil's ability to retain water depends on several soil characteristics such as its texture, soil organic matter (SOM) content and structure. It is linked to soil sealing, biodiversity, erosion and compaction.[8] Where soils are in good structural condition, the infiltration rate of water into the ground and the water-holding capacity of soil is higher. This in turn reduces flooding risk by reducing surface water run-off into water bodies. It also provides better conditions for crop growth.[8,38] As discussed in other sections, soil structure can be easily damaged through compaction, a reduction in SOM or a decline in biodiversity.[21] An additional 1% of flooding caused by soil compaction or sealing could increase local authority flood damage costs by £2.6 million per year and lead to insurance claims of £57-76,000 per property for a single flood event.[9]

4.29 During drought conditions, low levels of soil moisture content reduces the amount of water entering watercourses and poses a threat to drinking water availability. Soils become hydrophobic meaning that during storms water does not enter the soil and flash flooding can occur.[56,57] Soils appear to be disproportionately affected by drought with soil moisture dropping more than rainfall during dry periods. For example, a study in the Cairngorms during a period of drought in summer 2018 found that soil moisture was less than 50% of the summer average, despite rainfall only dropping by 37%.[58]

[4.30] Soil sealing in urban environments reduces the amount of water that infiltrates into soil, and can affect soil's ability to filter out contaminants from water, impacting surface water quality.[8] Surface water-run off, which has collected contaminants such as fertiliser, hydrocarbons and heavy metals and cannot infiltrate into soil due to sealing, may enter water courses directly, leading to surface water contamination.[59,8]

4.31 Climate change will also impact the moisture content of soils. Projected climate changes for 2070-2080 indicate that Scotland will face a drop in moisture content of 1-3% of field capacity (the amount of water retained in soil after excess water has drained). This compares to 3-5% in Denmark and an increase of up to 2% in Estonia and Western Sweden.[21] Scotland is expected to experience more frequent and more severe droughts due to climate change.

4.32 Between 1961 and 1990, Scotland had summer soil moisture at around 80-90% of field capacity, which is comparable to EU countries on a similar latitude.[21] However, Scotland compares unfavourably to Europe on other factors impacting water retention including compaction. In addition, biodiversity is in decline and there is the potential to increase soil carbon stocks, both of which impact water retention.[21]

4.33 No policy has been identified in Scotland relating to soil water retention capacity. Policies such as the Water Environment and Water Services (Scotland) Act 2003 and Water Environment (Controlled Activities) (Scotland) Regulations 2011 mention soil, but in relation to preventing a negative impact on groundwater quality. The Flood Risk Management (Scotland) Act 2009 does not contain any mention of soil. Soil water retention capacity is also not monitored in NSIS.

4.34 The reduction of soil capacity to retain water is a soil health indicator that the proposed EU Soil Monitoring Law will require member states to monitor. The criteria for this indicator will be set by Member States.[2]

Risk assessment – Medium: Climate change will lead to increased drought and flooding. Soils have the potential to mitigate some of these impacts in both urban areas and the wider countryside and to be part of a nature-based solution to mitigate the impact of climate change. However, the ability of soils in Scotland to retain water is expected to fall less than that in EU countries on a similar latitude. Soils' ability to retain water is intrinsically linked to other factors including compaction, erosion and soil carbon content which will be considered as part of the proposed analytical project detailed in the previous sections.

Risks to soil carbon

4.35 Soil contains both organic and inorganic carbon. Most soil carbon is organic (SOC) in the form of soil organic matter (SOM) derived from biological activity. Carbon levels vary according to soil type, with peatland soils (peat soil and some peaty soils) making a particularly significant contribution to Scotland's soil carbon stocks. SOM is essential to maintain many bio-chemical soil processes and their relationship with healthy soil biodiversity, it helps maintain good soil structure which in turn can reduce the risk of erosion and compaction.[60] It is also linked to soil fertility and nutrient levels, and climate change mitigation, adaptation and resilience.[17,61]

4.36 Carbon loss from soil can be in the form of greenhouse gas emissions, or as dissolved carbon into the water environment and particulate loss. All losses contribute to climate change, including particle and dissolved carbon loss due to breakdown. Through natural processes soils can sequester carbon. These processes can be enhanced to mitigate climate change (see Risk from Carbon Sequestration Schemes section).

4.37 SOM stocks in arable soils can decline for several reasons. Crops use organic matter from soil to support their growth. Harvesting of crops and removal of crops residues can deplete SOM if nutrient or fertiliser application via manures and organic materials such as sewage sludge, compost or anaerobic digestate is insufficient to replenish soil stocks. High tillage intensity (ploughing, rolling or cultivating soil with machinery), a lack of crop diversity and imbalanced use of artificial fertilisers can also lead to lower levels of soil carbon by disturbing other component of nutrient cycles.[61]

4.38 Long term data collection suggests that total soil carbon stocks, including in agricultural soils, appear to have remained stable over several decades in Scotland.[62,7] However, the time scale at which SOM changes operate (decadal) and the fragmented nature and scale of soil monitoring in Scotland means that there is uncertainty over trends in Scotland's soil carbon stocks and the potential for the existing data, which indicates that soil carbon levels are static, to be misleading.[7]

4.39 There is some clear evidence of a link between certain practices and changes to SOM, but no robust (statistically reliable) evidence for country level changes. Many of the changes are estimated via model prediction rather than direct measurements. This does not diminish the relevance of the direction of change, but makes it difficult to quantify the magnitude of the change. The largest long-term assessment of soil carbon levels identified in Scotland looked at up to 1,000 topsoil samples, but only in the north east of the country.[62]

4.40 EU wide, soils are overall losing carbon.[21] However, in Switzerland soils have absorbed more carbon from the atmosphere than they have lost in all but three years between 1990 and 2022.[63] This suggests that while Scotland compares well to the EU by potentially maintaining stable carbon stocks, there is the ability to achieve a positive trend in soil carbon stocks. Indeed, studies have found Scottish soils have the capacity to store more carbon.[7]

4.41 Scottish Government has recognised the importance of carbon storage and carbon sequestration in peat soil and pledged £250 million to restore 250,000 hectares of peatland between 2020 and 2030, to protect the existing resources and enhance its ability to capture more carbon from the atmosphere.[64] Between 2020 and 2023, around 35,000 hectares of degraded peatland has been restored and so the rate at which land is being restored will need to increase significantly if the 2030 target is to be met.[65] However, the 2024 Programme for Government confirmed that the ambition for the area of peatland to be restored in 2024-25 was only 10,000 hectares, half that of the previous target (20,000 hectares).[66,67] Nevertheless, the focus on peat soils is in contrast to the relative neglect of non-peat soils in legislation and policy. There are no targets for the restoration of non-peat soils and, as a result, non-peat soils have been the main focus of this report.

4.42 NPF4 aims to protect peatland and carbon-rich soils by allowing development and commercial peat extraction on such soils unless it is essential and only in certain circumstances and with a site-specific assessment. NPF4's policy intent in relation to soils is "to protect carbon rich soils, restore peatlands and minimise disturbance to soils from development".[49]

4.43 Other than those relating to peatland, no Scottish Government policy regulating soil carbon has been identified.

Risk assessment – Medium: Soil carbon stocks in Scotland appear to have been static for several decades. However, they can be improved and stocks in non-peat soils may be falling. As soil carbon has an impact on compaction and erosion rates

ESS will consider it in relation to those risks as part of the proposed analytical project detailed in the previous sections.

Risks from biodiversity loss

4.44 Soil provides a habitat for over half of the world's species, and in turn soil biota play a vital role in maintaining soil health and in the provision of soil services including releasing nutrients from soil organic matter (SOM), forming and maintaining soil structure and regulating soil infiltration and water retention.[21] Risks to soil biodiversity are linked to other soil risks including erosion, compaction, water retention, drought resistance and flooding potential.[8]

4.45 Soil biodiversity is threatened by multiple pressures. A synthesis of research from 107 European soil experts identified intensive human land use and exploitation of soil as the greatest potential threat to soil biodiversity.[68] The application of pesticides, fungicides, insecticides, synthetic fertilisers and other agrochemicals can have a negative effect on soil biodiversity.[69,70] Compacted soils are also likely to have lower biodiversity, with soils compacted by machinery and subject to tillage containing, on average, a sixth of the number of earthworms in soil farmed using no-wheel and no-tillage methods.[71] Erosion also redistributes seeds and microorganisms, changing biodiversity across an ecosystem.

4.46 While there is significant research on the impacts of particular practices and land use changes on soil biodiversity in Scotland, no overarching data on the proportion of soils at risk of biodiversity loss or on systematic monitoring of trends in soil biodiversity in Scotland have been identified. The only research identified relating to soil biodiversity in Scotland is small scale, examining the effects of using different fertilisers and other inputs. In the absence of trend data, it is not possible to determine if soil biodiversity is increasing or in decline. However, the Biodiversity Intactness Indicator does provide information on overall biodiversity in Scotland and indicates that: around half of historic land-based biodiversity has been retained in Scotland; and Scotland ranks in the bottom 25% of nations for overall biodiversity intactness.[72] The lack of soil specific data makes it difficult to determine the contribution that soil biodiversity is making to the overall biodiversity decline.

4.47 In comparison, EU-wide research has identified that in 14 out of 27 EU countries, 40% of soils are at moderate-high to high potential risk of soil biodiversity loss, with arable soils exposed to the most pressure.[68] The Swiss Soil Monitoring Network (NABO) is the only legally mandated soil monitoring network identified by ESS in Europe. NABO has gathered soil biodiversity data on microbial biomass, fungal and bacterial communities, environmental DNA (eDNA) and soil respiration since 2012.[73] After five years of monitoring, land-use related differences in microbiological parameters were found. However, changes over time in the parameters were typically small. An earlier NABO study noted that it can take six years before it can be determined if changes in the biodiversity parameters are caused by the environment.[74] It is not possible to compare trends in biodiversity between Scotland and Switzerland because data has not been gathered over a sufficient time period in Switzerland and there is no comparable data from Scotland.

4.48 Scotland's Biodiversity Strategy sets out goals to halt biodiversity loss by 2030 and restore biodiversity by 2045. The strategy includes a series of outcomes including that "soil health will be improved by tackling organic carbon loss, erosion and compaction to act as a nature-based solution to biodiversity loss*".* A monitoring and evaluation framework will be published alongside the final strategy and supporting delivery plan. This will set out how improvements in soil biodiversity will be assessed, although it is not clear at this stage what form this will take as no detailed monitoring regime or improvement plans are included in the Biodiversity Strategy. The proposed Natural Environment Bill and the Biodiversity Strategy will work alongside each other to set out statutory elements and policy to protect biodiversity.

4.49 The proposed EU Soil Monitoring Law will require member states to monitor soil biodiversity using soil basal respiration ($mm^3\ O_2\ g^{-1}\ hr^{-1}$) in addition to some optional parameters.[2] Consultation feedback to the proposal highlighted that soil basal respiration rate is an indicator of microbial or metabolic activity and not an indicator of biodiversity and so may not be an appropriate metric.[75] Additionally, the EU's proposed Nature Restoration Law uses soil organic carbon in cropland soils as an indicator for biodiversity.[3]

Risk assessment – High: Biodiversity is in decline in Scotland, but no overarching, national scale studies or surveys on soil biodiversity and how it is changing over time have been identified. Studies tend to focus on the impact of particular inputs on biodiversity. The impact of soil biodiversity loss is significant, impacting soil health and the wider environment. However, the absence of research in this area means any value ESS can add is low until further evidence emerges. ESS has recommended that Scottish Government, in association with the wider public sector (e.g. NatureScot, SEPA and Scottish Forestry amongst others), commission further research into soil biodiversity, including rates of change in soil biodiversity. This would be supported by monitoring introduced as part of legislation to keep pace with the EU Soil Monitoring Law, which will help build the evidence base for a range of soil properties which impact soil biodiversity.

Risks from soilborne diseases and pests

4.50 Soils are a vector for diseases and pests that pose risks to plants, crops and to national food security. Wild plants and forests (both natural and farmed or productive forestry) are at risk from soilborne diseases and pests. Climate change may increase the risk of soilborne pathogens to trees. Milder and wetter winters make the survival of pathogens more likely, increasing the risk of disease in trees.[76]

4.51 In Scotland, plant health controls are based on the EU Plant Health Regime and are implemented by the Plant Health (Official Controls and Miscellaneous Provisions) (Scotland) Regulations 2019.[77] The regulations require soil testing prior to planting of seed potatoes and a selection of rooted plants, bulbs, tubers and rhizomes plants to prevent the establishment and spread of all plant pests. To proceed with planting, potato cyst nematodes (PCN) must be absent.[78]

4.52 PCN and other notifiable diseases are monitored by Science and Advice for Scottish Agriculture (SASA). The Plant Health Centre undertakes research into plant health threats in Scotland and provides scientific evidence to the Chief Plant Health Officer Scotland to inform policy decisions. SASA and the Plant Health Centre monitor and research other non-notifiable, known and emerging diseases and pests. This includes research on diseases and pests which have not yet been detected in the UK such as '*Xylella fastidiosa'*, a bacteria spread by insects.[79]

4.53 Ministers have been active in responding to soilborne diseases and pests. The PCN working group was formed in 2020 and has made recommendations for Scottish Government. The working group identified that 13% of land used for growing bulbs and potatoes was infested with PCN, and that this is increasing in spread by 5% per year with the potential for no seed potato or bulb production in

Scotland by 2050.[80,81] However, infestation rates in Scotland compare favourably to England and Wales, although the country's status as a producer of seeds means the spread is potentially more concerning.[81] The government has responded to the PCN working group's recommendations by launching a project to research PCN and limit its spread.

4.54 The Scottish Biodiversity Strategy will aim to protect and support the recovery of vulnerable and important species and habitats (objective four of the Strategy) by supporting "surveillance and monitoring to manage pathogens and disease risks". A new Scottish Plant Health Strategy will be published in late 2024.[72] Scotland's 2012 non-native species code of practice also defines how soils should be moved to prevent the spread of nonindigenous flatworms.[82]

4.55 While not linked specifically to organisms identified as pests, bioturbation (the disturbance of soil by living organisms, particularly roots) and aggressive soil environments (e.g. soils with high acidity or sulphate content) were also identified as threats posed by soil to archaeology close to the surface.[54]

Risk assessment – Low: The Plant Health Centre and SASA carry out studies on emerging diseases and the findings are available on their websites. The Centre has also carried out a project to improve its communications with stakeholders which should improve access to information for farmers. ESS is therefore satisfied that sufficient work is being done in relation to soilborne diseases and pests and no further work by ESS in this area is proposed.

Risks from contamination

4.56 Soil contamination is widespread across Scotland. It is predominantly a consequence of industry, but also arises from other human activities and atmospheric nitrogen deposition. Contaminated soil may impact soil biota, groundwater, surface water and drinking water supplies, risking human health, and aquatic life. Atmospheric nitrogen deposition poses a potential risk of soil acidification, eutrophication and an increase in toxicity to organisms living in semi-natural soil.[83]

4.57 The geographic distribution of soil contamination varies in Scotland. For example, concentrations of heavy metals are significantly higher in urban soils in

Glasgow and the Clyde Basin compared to rural areas. There is also a geographical association between soil metal concentrations and areas of deprivation.[84]

4.58 The release of contaminants in Scotland is regulated by a range of legislation such as the Water Environment (Controlled Activities) (Scotland) Regulations 2011 and the Environmental Protection Act. Under Part 2A, where a local authority identifies that because of substances in or under the land and there is a risk of significant harm to the health of living organisms or ecological systems, or pollution to the water environment or harm or pollution is occurring, the land becomes legally defined as contaminated land.[29]

4.59 Local authorities are required by Part 2A to identify and investigate potentially contaminated sites. If the site is formally identified as contaminated, the local authority must place the site on a publicly available contaminated land register and the identify appropriate person who is then required to pay for and carry out any remediation. The local authority may designate a site as a special site, in which case SEPA becomes the enforcing authority and responsible for securing remediation. For example, special sites may have been where activities requiring Integrated Pollution Controls have been carried out.

4.60 During stakeholder engagement for this report, it was suggested that some local authorities are not identifying sites under Part 2A or putting contaminated sites on a register. Stakeholders, including local authorities and contaminated land specialists, suggested several reasons for this such as: sites on the contaminated land register being difficult to sell and becoming a blight on the community; the removal in 2014 of ringfenced funding for investigations (funding was incorporated into the block grant under the Single Outcome Agreement); and the fact that the planning system is deemed effective at identifying and remediating most contaminated sites without being a burden on the taxpayer. A local authority in England has also stated that it is not identifying sites as it lacks the technical capability, resources and funding.[85]

4.61 A UK Government report found that between 2000 and 2013 an estimated 72,000 contaminated sites were ‘dealt with’ through planning applications compared to 5,500 sites handled through Part 2A in England and Wales, although exact details of what sites being dealt with entails are not provided.[86] In Scotland, SEPA stated that 807 sites were remediated via local authorities’ planning systems or through 36 voluntary remediation and that 13 sites were designated under Part 2A between 2000 and 2008, of which three were designated as special sites. In lieu of a more contemporary report, it is uncertain what progress has been made since 2008.[87]

4.62 Scotland's Planning Advice Note on Development on Contaminated land does not set out any requirements for maintaining a public register of contaminated land identified through the planning process, noting that definition of contaminated sites differs in a planning context to that under Part 2A. Part 2A does allow for effective intervention should a site require inspection by a local authority where a potentially contaminated site is identified as part of the planning process.[88] Aggregated data on contaminated sites using the information from planning applications is not routinely produced by local authorities.

4.63 In 2013, the Institute of Environmental Scientists concluded that Part 2A is not wholly fit for purpose because local authorities are using other legislative avenues to remediate land. This tends to be through planning, but the guidance used (Planning Advice Notice 33) is not legislation.[89,90]

4.64 Without a comprehensive contamination register, it is not possible to assess the overall risk to the environment and human health of contaminated sites. Historically contaminated sites are likely to be vacant, with people unlikely to spend sufficient time at such sites for the contamination to pose a direct health risk.[91] However, historic contamination may pose a risk to surface and groundwater and subsequently to the aquatic environment and drinking water supplies.

4.65 In terms of managing contamination from atmospheric deposition, Scotland has established a nitrogen balance sheet to address the nitrogen loss from and deposition to soil. Scottish Government continues to develop the nitrogen balance sheet and monitoring programme to support and develop new policies to minimise losses to and from the environment (although the policy is relatively new) and the effects have not yet been observed.[92]

4.66 The proposed EU Soil Monitoring Law will require member states to update the Commission and European Environment Agency (EEA) on progress on the registration, investigation and management of contaminated sites every five years.[2]

Risk assessment – Medium: Local authorities may not be fulfilling their duties under Part 2A which may be a compliance issue. However, this may be because of ineffective legislation. The risk posed by unidentified contaminated sites is also unclear. ESS has therefore begun investigatory work on the application and effectiveness of Part 2A. ESS will monitor progress with implementation of the nitrogen balance sheet and the effectiveness of associated policies.

Risks from soil sealing

4.67 Soil sealing occurs when the ground is covered by an impermeable material such as concrete, tarmacadam or buildings or rendered impervious (by excessive surface compaction/degradation). Once soil is sealed its functionality is lost to the ecosystem and certain environmental risks increase. These include an increased risk of flooding, transmission of pollutants and water scarcity because of rapid surface water run-off into surface waterbodies instead of slower infiltration into the soil and groundwater reserves.[93] Soil sealing can also put biodiversity at risk, remove fertile soil from biomass production and reduce the amount of soil available for carbon sequestration.

4.68 An EU and UK wide study found that 20% of the soil sealed between 2012 and 2018 was of high biomass productivity potential. The total estimated loss of carbon sequestration potential for the whole of EU was estimated at 4 million tonnes and causing an estimated loss of 668 million m^3 of water retention capacity.[27] An additional 1% of flooding caused by soil sealing could increase local authority flood damage costs by £2.6 million per year and lead to insurance claims of £57-76,000 per property for a single flood event.[9]

4.69 Other studies have also found that soil sealing poses a threat to UK soils by significantly affecting soil hydrological and microbial functions, although few studies have been carried out on the effect on other soil functions.[94]

4.70 In Scotland, the total amount of soil sealed (in urban areas and the wider countryside) in 2019 reached almost 2% of total land mass, increasing from around 1.4% in 2009, with a maximum amount of soil sealed of almost 6% in the Forth catchment.[25] This is roughly equivalent to the amount of sealed land in the EU, which was 2.3% in 2018.[26] Between 2009 and 2020, the amount of soil sealing in Scotland increased by around 22%.[95]

4.71 The type of land being sealed is important. However, if the land being sealed is prime agricultural land, then its loss is significant for food production. Soil sealing has been monitored at intervals between one and four years since at least 2009 and is reported on the Scotland's Environment website.[25]

4.72 There is no legislation in Scotland to regulate soil sealing. However, NPF4 Policy 5 states that "development proposals will only be supported if they are designed and constructed […] in a manner that […] minimises soil sealing".[49]

4.73 The EU Soil Monitoring Law proposed to address the amount of soil sealing by mandating that member states monitor land take and sealing. The method of measuring land take would be left to the member state, but must be based on scientific literature or be publicly available.[2] Member states should assess the impact of sealed land on the loss of ecosystem services and report a trend analysis every five years.[2]

4.74 The law proposes that where land take occurs, Member States must: reduce the area affected; select areas where the loss of ecosystem services will be minimised; and perform the land take in a way that minimizes the negative impact on soil by (for example, minimizing the area of sealing). The law will also require compensation, most likely in the form of offsetting, for the loss of soil capacity to provide ecosystem services.[2] The EU aims to have no net land take by 2050, a target mirrored by the Swiss National Soil Strategy.

Risk assessment – Low: Scotland compares favourably to the UK and the EU in terms of the amount of land sealed and the increase in rates of land sealing. Scotland reports regularly on the amount of land sealed. However, sealing is a potential future risk, which can pose a significant risk of flooding and economic damage in urban areas and could be addressed with adequate changes in policy and monitoring. By adopting the policies related to soil sealing in the proposed EU Soil Monitoring Law which aim to offset the negative impacts of land sealing, Scotland has the opportunity to limit the effects of future soil sealing. ESS recommends that Scottish Government bring forward legislative proposals regarding data and monitoring as part of the commitment to keeping pace with EU law, specifically the proposed Soil Monitoring Law, and will monitor their response.

Risks from landfilling of waste soil

4.75 In 2022, around a quarter of the material disposed of in landfills in Scotland was soil, despite soil being a non-renewable resource. This soil comes from commercial and industrial sources, as well as household, construction and demolition activities. Over 99% of the soil treated as a waste is excavated during construction.[24] Stakeholders engaged in this report perceived that it often costs less to dispose of soil than reuse it and opportunities for soil recycling in Scotland are limited.

4.76 There are direct environmental impacts from removing and disposing of soil in landfill. These include removal of biomass, soil carbon, and most of the seedbank and nutrients from an ecosystem. The soils most likely to be removed are surface soils excavated during construction.[24] Surface soils, particularly topsoils, contain the highest carbon levels, nutrients and organic matter, as well as most of the microbial and fungal biomass and viable seeds.[96] Once soil is buried in landfill, soil functions are lost – it starts losing nitrogen, sulphur and carbon.[97] The Environment Agency has stated that "once soil is lost, its ability to deliver its functions is very difficult to retrieve and, in the long-term, this could be catastrophic".[98]

4.77 Soil removal and disposal in landfill also has indirect environmental impacts. These include greenhouse gas emissions from transporting soil offsite and, at developments where soils are removed to protect human health or the water environment as part of remediation work, from transporting uncontaminated soils to replace those that have been removed. The use of aggregate to replace removed soil has environmental impacts from the quarrying, crushing and grading processes. In addition, the expansion of landfill sites damages landscapes. As discussed earlier in this report, movement of soil can also alter soil biodiversity and spread diseases and pests.

4.78 In Scotland, the construction industry produced 2,981,523 t of the 3,012,570 t of soil waste generated in Scotland in 2022. Approximately, 639,000 t of soil were landfilled in 2022, with construction industry being the largest contributor of landfilled soil.[24] The volumes of soil disposed of in landfill in Scotland in 2022 were equivalent to the average annual losses from erosion of up to 2,672 km^2 of agricultural land, an area larger than Lanarkshire.[24,51] In England and Wales in 2018, ten times the amount of soil lost to erosion was disposed of in landfill.[99]

4.79 Alternatives to landfilling waste soil, which have the potential to reduce or mitigate the direct and indirect environmental impacts discussed above, include onsite remediation and recycling of soil waste. The rates of waste soil recycling and landfill disposal in Scotland vary according to whether it is classified as 'hazardous' or 'non-hazardous' waste under SEPA's WM3 Waste Hazard Assessment guidance.[100]

4.80 Hazardous soils can be recycled for reuse on sites following cleaning of contamination. In Scotland, the proportion of hazardous soils recycled, relative to landfill disposal has varied substantially across the period 2011-2022, ranging from 2.3% in 2012 to 62.3% in 2017 (Figure 4-3). In the most recent two years for which data are available (2021, 2022), no hazardous soils were recycled in Scotland. The amount of hazardous soils sent to landfill in 2021 and 2022 was also two out of the lowest three volumes disposed of between 2011-2022.[24]

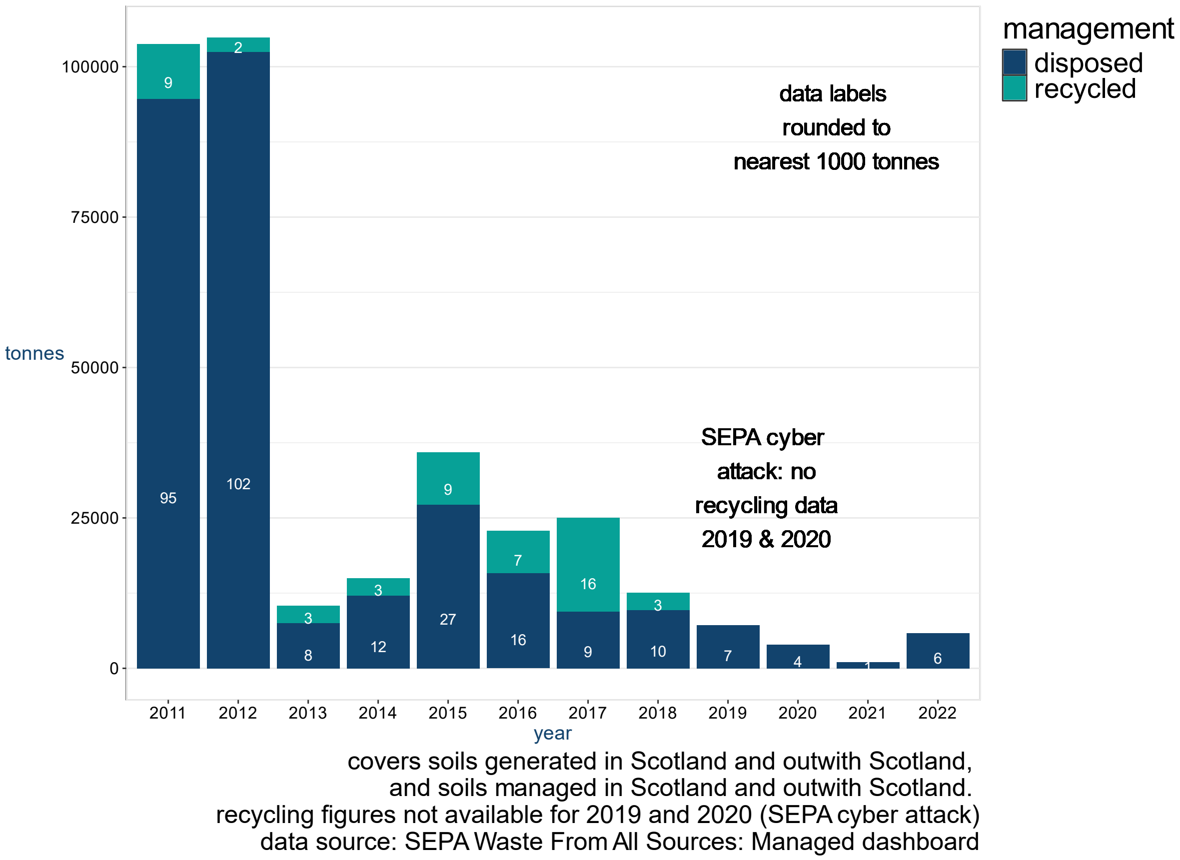


Figure 4-3: Management of hazardous soil waste. Tonnage of hazardous soils recycled or disposed of in landfill, including soils generated within and outwith Scotland, and soils managed in and outwith Scotland. Data source: SEPA Waste from All Sources Managed database.[24]

4.81 Non-hazardous soil waste can also be recycled. In Scotland, the proportion of non-hazardous soil waste that is recycled, relative to landfill, was higher and less variable that that of hazardous soil waste between 2011-2022 (Figure 4-4). The highest proportion recycled was 78% in 2022, and the lowest was 54% in 2021. Non-hazardous soil waste that is disposed of in landfill is also subject to 'Waste Acceptance Criteria' analysis that determines whether the waste can be disposed of in an 'inert', 'non-hazardous' or 'hazardous' landfill according to the concentration of particular contaminants or the presence of other materials.[101]

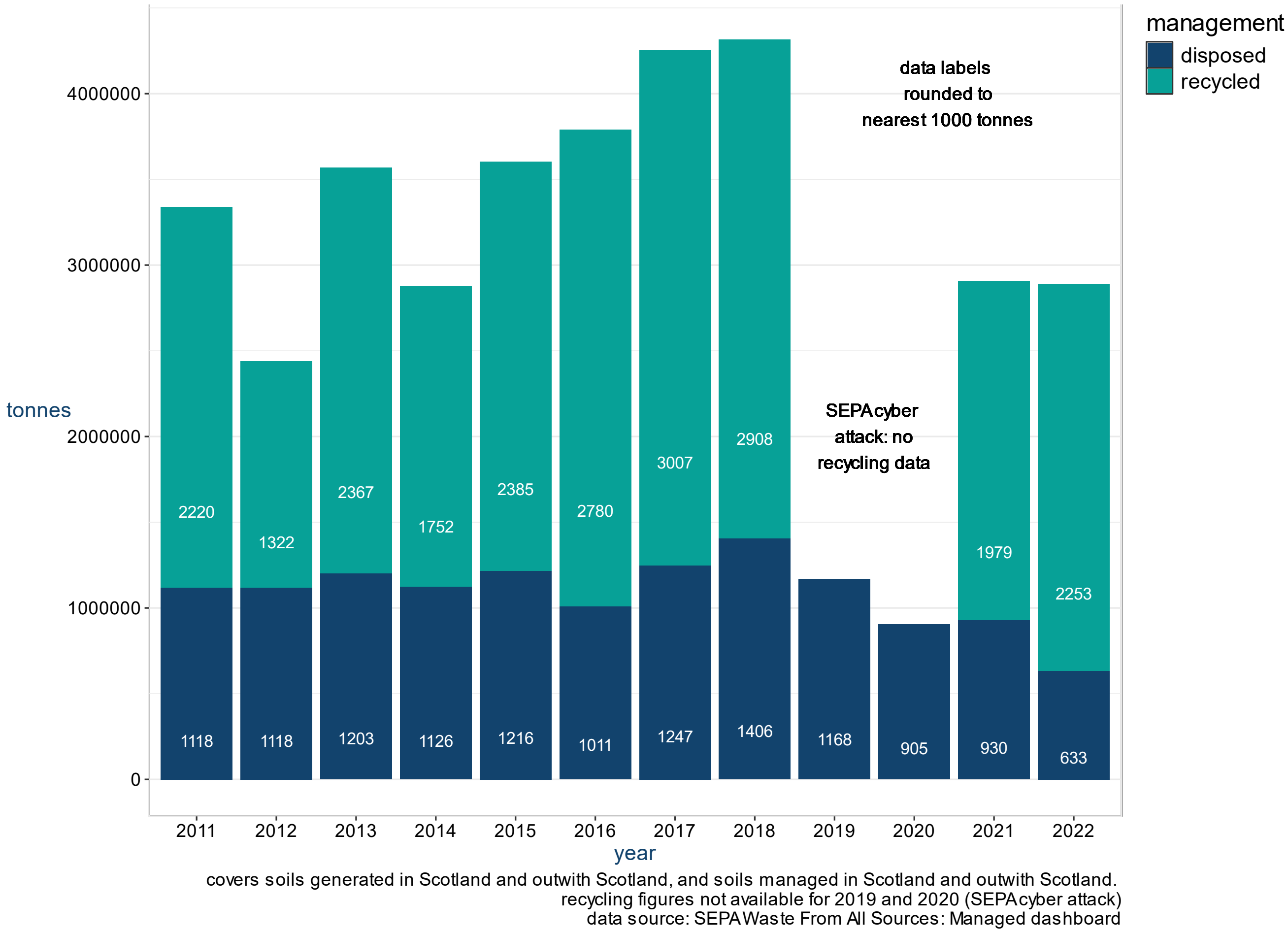


Figure 4-4: Management of non- hazardous soil waste. Tonnage of hazardous soils recycled or disposed of in landfill, including soils generated within and outwith Scotland, and soils managed in and outwith Scotland. Data source: SEPA Waste from All Sources Managed database.[24]

4.82 There are a variety of drivers that determine whether both hazardous and non-hazardous soil waste is recycled or landfilled in Scotland. A detailed review of these drivers and their relative importance is beyond the scope of this report. Soils sent to landfill are subject to landfill tax at rates set out in guidance from Revenue Scotland.[102] It is conceivable that applying a lower rate of tax to certain categories of soil may act as a disincentive to recycling and reuse. Further analysis would be required to determine whether, and to what extent, this is the case in practice.

Risk assessment – Medium: The loss of soil to landfill poses several risks to the services provided by soil and the wider environment. ESS will continue to monitor available data on rates of recycling and landfilling of soils in Scotland and will undertake any further analytical or investigation work as appropriate.

Risks from the application of waste to land

4.83 In recent years, the has been an increase in the application of waste products to improve soil nutrient concentrations in Scotland.[103] This includes use of anaerobic digestate and sewage sludge. Application of waste to land can introduce contaminants to soil and affect soil biodiversity. This, in turn, poses risks to human health through contaminated drinking water or food supply, and may impact ecosystem process and functions. The application of sewage sludge is also a source of microplastic contamination. One study has estimated that between 7.2 and 149 trillion plastic particles may be spread onto agricultural land across the EU in sewage sludge.[104] However, spreading of these materials aligns with circular economy goals and, in the absence of current alternative uses, sludge not spread on land tends to be incinerated.

4.84 The proportion of sewage sludge spread on land is relatively low in Scotland. Sewage sludge makes up 1.7% of the total waste spread on land, with the majority of the remainder (over 86%) being animal manure and slurry.[103] The spreading of both anaerobic digestate and sewage sludge in Scotland is regulated by SEPA. Anaerobic digestate spread on land must be certified to SEPA’s end of waste position which is based on the British Standards Institute Publicly Available Standard 110 or be subject to SEPA’s waste regulatory controls.[105] The use of sewage sludge on agricultural land in Scotland is regulated by the 1989 Sludge Use in Agriculture Regulations. Spreading on other land is controlled by SEPA’s waste regulatory framework.

4.85 Prior to spreading, sludge must be tested for the parameters in Table 4-1: UK sewage sludge testing parameters.[106] However, there are additional contaminants that may be present in sewage sludge which are not tested for under the regulations. These include Per- and Polyfluorinated Substances (PFAS) which have contaminated drinking water and soil in other countries. Following contamination incidences, involving chemicals including PFAS which led to the poisoning of water, beef and milk, Switzerland, the Netherlands and some US states banned spreading of sewage sludge.[107,108]

UK Sewage Sludge Testing Parameters	
Chemical parameters	Other parameters
Chromium	pH
Zinc	Dry matter
Copper	Organic matter
Nickel	Nitrogen
Cadmium	Phosphorus
Lead	
Mercury	

Table 4-1: UK sewage sludge testing parameters.[109]

4.86 Information on organic contaminant contamination as a result of sewage sludge in Scotland is limited. No primary research studies have been identified that assessed contamination associated with sewage sludge spreading in Scotland. SEPA and CREW have carried out reviews and conclude that there are no causes for concern to human health, although the SEPA review was preliminary and CREW states that it remains unknown if there is a risk of PFAS contamination associated with sewage sludge spreading.[110,111,112]

4.87 No incidents of organic contaminant contamination like those in the US or Germany have been identified in Scotland by ESS. Similarly, no evidence has been found of groundwater acidification, leaching or eutrophication in Scotland and, provided that there is good practice management, there is little evidence of a direct link between sludge application and the microbiological quality of groundwater.[113, 114,115]

4.88 In 2015, the Scottish Government commissioned a review of sewage spreading. It concluded that there were no proven health risks with spreading and that it was a more efficient and sustainable alternative to artificial fertilisers. The review made a significant number of recommendations relating to spreading practice, handling of complaints, regulation or operators, powers to stop problematic activity, storage, monitoring and quality of sludge. The recommendations relate to spreading practices, public nuisance and human health rather than soil and are therefore outside the scope of this report. The report did consider soil, but found there was not enough evidence to properly assess the risk to soil.[116]

4.89 In a review of the Sludge Directive in 2023, the EU concluded that the set of pollutants regulated in sewage sludge needs to be reviewed, notably considering organic contaminants, pathogens, pharmaceuticals and microplastics. The review also concluded that there is a lack of data on the environmental impact of spreading sewage sludge.[117]

Risk assessment – Medium: There is limited evidence available of negative impacts on soil and the environment in Scotland from sewage sludge spreading and studies specific to Scotland have not been able to reach conclusions on the risks, although soils have been significantly impacted in the US. At this stage, the lack of evidence makes it difficult to make recommendations regarding changes to the use and testing of sewage sludge. While the risk assessment score is medium, the evidence base must be built before further conclusions can be reached. ESS will continue to monitor this area and will consider further action if new evidence comes to light. ESS has recommended that Scottish Government, in association with the wider public sector (e.g. NatureScot, SEPA and Scottish Forestry amongst others) commission research to address identified gaps in the evidence base including the environmental impacts of spreading waste on land.

Risks from carbon sequestration schemes

4.90 Carbon sequestration schemes are intended to capture and store carbon dioxide from the atmosphere with the aim of reducing climate change. Schemes may include increasing below ground carbon stores (SOC) content or storing carbon in the above ground biomass of plants and associated root systems. Storing carbon in soils, in particular in carbon rich peatland soils, is a key aspect of the Scottish Government's Climate Change Plan and the EU's Soil Monitoring Law.[2,20]

4.91 Carbon sequestration through tree planting will also help to meet Scotland's net zero by 2045 target and the Climate Change Committee has highlighted "support [for] agroforestry and hedgerows on Scottish farms" as an area where Scotland can do more. However, limited evidence on the impact and effectiveness of tree planting in relation to soil was found as part of this review and the conclusions are varied depending on initial soil carbon status. Studies in Scotland and the US found that tree planting can in fact reduce SOC to the point that the amount of carbon in the whole ecosystem drops and trees planted on organo-mineral soils may not result in net carbon sequestration for decades due to soil disturbance.[118, 119,120]

4.92 Carbon may also be sequestered in grassland soils and farmers can sell carbon credits to private companies under the Peatland Code. However, studies in Scotland have found these soils to have the lowest carbon stocks and any sequestered carbon can be lost if soils previously in a sequestration scheme are then removed from the scheme and, for example, ploughed.[120] A loss of SOC due to tree planting for sequestration has the potential to impact other soil properties. Lower SOC can lead to increased compaction and erosion and a drop in biodiversity, as discussed earlier in this report.

4.93 In Scotland there is no regulation of carbon sequestration schemes, although voluntary codes such as the Peatland Code and Woodland Code do exist. The EU has provisionally agreed a carbon removals certification framework. This voluntary framework aims to certify high quality sequestration schemes including those restoring forests and soil and reducing soil carbon emissions. The framework requires certified sites to carry out monitoring and will make operators liable for any releases of carbon into the atmosphere.[121]

Risk assessment – Medium: In the absence of clear evidence on the impact of carbon sequestration schemes it is not possible to reach a conclusion on the risk these schemes pose to soil health, particularly soil carbon content, and the service provided by soil. While voluntary schemes such as the Peatland and Woodland Codes exist, there is a lack of mandatory regulation of carbon sequestration schemes, but without further research and monitoring it will be difficult to design a suitable regulatory framework. There is a potential keeping pace issue if the EU takes forward proposals for a carbon removals certification framework. It is considered that ESS' added value of analytical work here is low until further research emerges. ESS has recommended that Scottish Government, in association with the wider public sector (e.g. NatureScot, SEPA and Scottish Forestry amongst others) commission research to address identified gaps in the evidence base including the impact on soil of carbon sequestration schemes.

Risks from the inconsistent approaches to data collection and monitoring

4.94 Soil surveying provides information on soil condition and degradation and can be used to ensure that risks to soil health are understood and prevented. Repeated surveying, as part of a monitoring programme, allows trends in soil condition that pose a risk to the wider environment to be identified.[8] Monitoring data can be used to assess whether changes in legislation or technology have improved soil health.

4.95 Other European countries have established successful monitoring schemes. NABO, Switzerland's legally mandated soil monitoring network, has monitored 100 sites at five-year intervals since 1985.[122] The findings underpin recommendations to Swiss policy makers and have been used to identify negative trends in soil condition.[123] Similarly, Northern Ireland launched the Soil Nutrient Health Scheme to monitor all fields in Northern Ireland every four years. The data will be used by Northern Ireland to provide a baseline assessment of soil carbon, with the intention that the data will support a to transition to Net Zero farming.[124]

4.96 The proposed European Soil Monitoring Law will require member states to take soil measurements and health assessments, and to report their monitoring data to the European Commission and EEA every five years. Annual updates to land and soil sealing indicators will be required.[2] In addition, the EU Nature Restoration Law will require member states to monitor the stock of organic carbon in cropland mineral soil.

4.97 The lack of a Scottish soil monitoring regime has led to a lack of data on many of the risks identified in this report. This means it is difficult to reach conclusions on the state of soil and the risks posed to it, and to make recommendations for improvements. There is a potential keeping pace issue in relation to the proposed EU Soil Monitoring Law without overarching legislation in Scotland on soil health.

4.98 The lack of a consistent soil monitoring regime has led to a range of different parameters being used to measure soil in Scotland. The inherent inconsistency in survey programmes, means that establishing a relevant baseline from which to monitor changes in soil is challenging.

4.99 Consistent soil health indicator metrics allow different sets of monitoring data to be easily compared and to assess trends. Establishing a comprehensive suite of metrics also ensures that no important aspects of soil health are missed during monitoring.

4.100 Several attempts to determine a set of metrics to monitor have been made. The 2003 UK soil indicator Consortium[125] led by Environment Agency (EA), Joint Nature Conservation Committee (JNCC) 2023 report[126], NABO, ClimateXChange, James Hutton Institute and the EU have all created lists of metrics. There is disparity between all of them in terms of the specific metrics, but they generally all assess the soil's physical and chemical properties and nutrients. The JNCC, NABO and proposed EU Soil Monitoring Law also consider indicators for biodiversity. To date, only the NSIS and NABO metrics have been used in nationwide monitoring schemes. These are summarised in Table 4-2.

Indicator	NSIS1 (1978) & NSIS2 (2007) [127]	NABO (1985 onwards) [128]	Environment Agency (2006) [129]	JNCC (2023) [130]	EU Soil Monitoring Law (2023)[2]	ClimateXChange (2021) [131]	Northern Ireland Soil Nutrient Health Scheme (2023)[124]
Soil physical properties (compaction, water retention, erosion, structure etc.)							
Electrical conductivity					X		
Exchangeable cations	X						
Base cations	X						
Loss on ignition	X						
Soil erosion rate					X		
Aggregate stability				X			
Grain size content	X						
Soil structure and aggregate distribution				X			
Soil compaction		X					
Bulk density/porosity		X	X	X	X	X	
Bulk density in topsoil					X		
Infiltration/hydraulic conductivity				X			
Soil water retention		X		X	X		
Water and air flow		X					
Moisture content						X	
Topsoil depth						X	
Visual evaluation of soil structure						X	
Erosion features						X	
Soil nutrient content							
Extractable phosphorus/phosphate	X		X		X		X
Nutrient content		X					
Hydrogen and aluminium content	X						
Sodium content	X						
Calcium content	X						
Magnesium content	X						X
Potassium content	X						X
Soil nitrogen	X		X	X	X		
Nutrient flux						X	
Sulphur content							X
Soil chemical properties (contamination, carbon content etc)							
Soil contamination (heavy metals + organic contaminants)		X			X		
Copper, nickel and zinc			X				
Soil acidity	X		X	X	X		X
Soil organic matter/carbon	X	X	X	X	X	X	

Indicator	NSIS1 (1978) & NSIS2 (2007) [127]	NABO (1985 onwards) [128]	Environment Agency (2006) [129]	JNCC (2023) [130]	EU Soil Monitoring Law (2023)[2]	ClimateXChange (2021) [131]	Northern Ireland Soil Nutrient Health Scheme (2023)[124]
Dissolved organic carbon						X	
Biodiversity indicators							
Soil basal respiration (indicator for biodiversity)		X		X	X		
Water and air flow		X					
Microbial biomass		X		X			
Fungal and bacterial community composition		X		X		X	
Earthworms				X		X	
Functional genes						X	

Table 4-2: Soil health indicator metrics from NSIS, Swiss National Soil Monitoring Network (NABO), Environment Agency, Joint Nature Conservation Committee (JNCC), Proposed EU Soil Monitoring Law and Northern Ireland Soil Nutrient Health Scheme (SNHS).

4.101 The Soil Monitoring Action and Implementation Plans produced following the State of Scotland's Soil report do not include a list of metrics. Scotland's Soils website states that at the time "these [plans] recognised it was not possible to set up a one-size-fits-all monitoring programme across Scotland". [132]

4.102 Establishing a mandatory soil monitoring network with a consistent set of indicator metrics will allow trends in soil to be monitored in Scotland. Determining which metrics to use is beyond ESS' remit and expertise. Failing to adopt the metrics from the proposed EU Soil Monitoring Law, with additional Scotland-specific metrics added if required, is a potential keeping pace issue.

Risk assessment – High: In the absence of a single, systematic monitoring regime with regular repeat sampling in Scotland, scientists, forest managers and farmers cannot track trends in soils and an assessment cannot be made on the extent to which policy changes relating to soil are effective in improving soil health. This could be rectified if Scotland's commitment under the UK Withdrawal from the European Union (Continuity) (Scotland) Act 2021 to keep pace with EU law are met and a monitoring regime meeting the requirements of the proposed Soil Monitoring Law are adopted.

4.103 Without a consistent set of health indicator metrics, the ability to compare monitoring data to identify trends over time and across areas is limited. In light of the proposed EU Soil Monitoring Law this is a potential keeping pace issue.

4.104 ESS recommends that Scottish Government bring forward legislative proposals regarding data and monitoring to, as a minimum, keep pace with the proposed EU Soil Monitoring Law and will monitor their response.

Annex 1 – Full list of stakeholders contacted

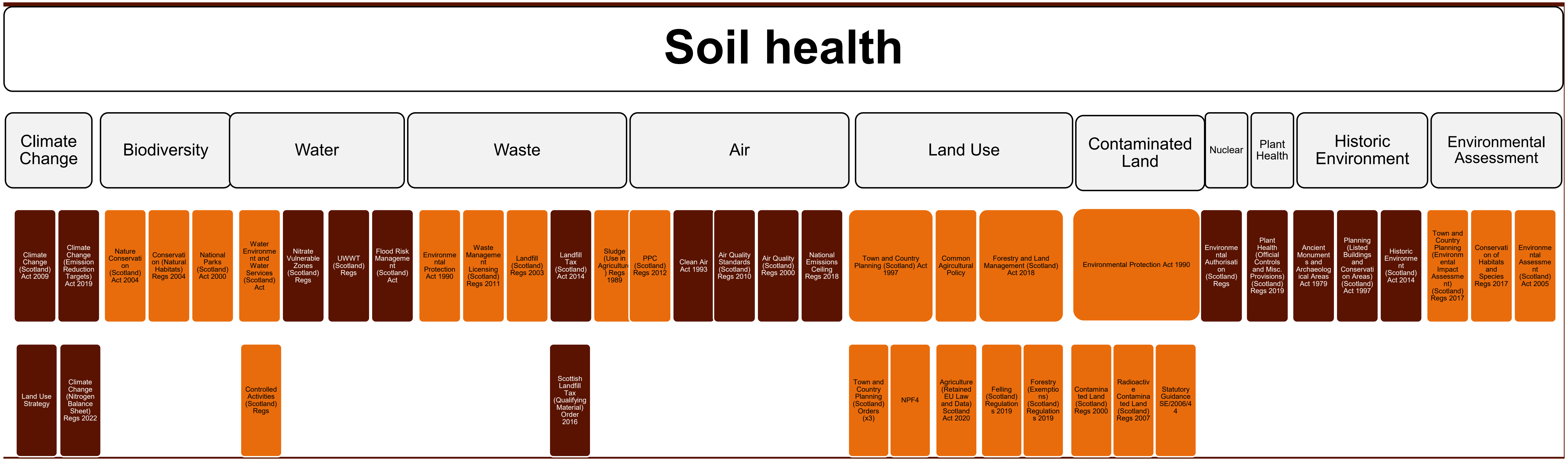
Consultees		
Government organisations	**Non-government organisations**	Private sector companies and professional bodies
Scottish Environment Protection Agency (SEPA)*	Scotland's Rural College (SRUC)*	Scottish Contaminated Land Forum*
Nature Scot*	The Soil Association*	4R Group*
Fife Council Environmental Health*	National Farmers' Union (NFU)*	Farm Carbon Toolkit*
Perth and Kinross Council Environmental Health*	Scottish Land and Estates (SLE)*	British Society of Soil Scientists*
British Embassy Berne*	James Hutton Institute (JHI)*	Leapmoor Environmental*
Scottish Government Environmental Quality and Resilience*	Centre of Expertise for Waters (CREW)*	ERS Remediation Ltd
British Geological Survey (BGS)	Scottish Environment Link*	Soilutions Ltd*
Federal Office for the Environment (FOEN) (Switzerland)*	Nature Friendly Farming Network	Bayne Stevenson Associates Ltd
Forestry and Land Scotland	Nourish Scotland*	RSK Group
Scottish Forestry*	British Agricultural Bureau*	Mason Evans
	National Trust for Scotland*	Entrust Environmental*
	Innovative Farmers	RPS Group
	Forest Research	MM-EC Ltd
	Future Woodlands	Basis Registration Ltd
		Enva Scotland Ltd

*Stakeholders who responded

Annex 2 – Legislation relating to soil in Scotland

Key:

Strong influence	Direct remit and strong effect.
Moderate influence	Direct remit and limited effect. OR Indirect remit and strong effect.
Limited influence	Indirect remit and limited effect.



Annex 3 – Risk prioritisation matrix

Risk scoring criteria

Based on ISO14001:2015 Environmental Management Systems Criteria

Category	Score		Criteria
Likelihood	High		High chance of occurrence
	Medium		May happen at some time
	Low		Very unlikely to occur
Severity	High		Significant effect (short or long term) which is widespread throughout Scotland
	Medium		Some effect locally
	Low		No or slight localised effect
Certainty	Low		Nothing or very little is known about the topic or its consequences
	Medium		Something is known about the topic or its consequences
	High		A good amount is known about the topic or its consequences
Added value	Low		Limited – intervention unlikely to result in significant change
	Medium		Intervention likely to bring positive change and help resolve issue
	High		Intervention to bring substantial positive change and resolution of issue

		Application of waste to land	Biodiversity	Carbon sequestration	Compaction	Contamination	Data and monitoring	Disease and pests	Erosion	Landfilling of waste soil	Soil carbon	Soil sealing and development	Water retention and drought resistance
	Definition	**Spreading of waste material in agriculture and Paragraph 9 and 19 exemption landfill sites**	**Soil biodiversity and the services soil biota provide**	**The impact on soil of tree planting to sequester carbon and using soil to sequester carbon. Peat is not included.**	**Damage to soil structure caused by machinery and livestock, reducing pore space**	**Materials introduced by human activity to soil which pose a risk to human health and the environment**	**Gathering information about soil at regular intervals**	**Soil-borne pests and diseases impacting crops**	**Loss of soil due to wind, water and wind abrasion**	**Excavation and disposal of soil to landfill**	**Carbon stored in soil (excluding peat, but including peaty soils) as organic matter or minerals**	**Covering soil with impermeable surfaces**	**The ability of soil to absorb water and storage of water**
Likelihood x severity	**IMPACT** How significant is the risk to and potential impact on the environment and human health?	High	High	Medium	High	High	High	High	High	Medium	High	Medium	High
Certainty	**NATURE AND SCOPE** Does ESS know what the status is? Is it getting better or worse? Is it being monitored?	Medium	Low	Medium	Low	Medium	Medium	Medium	Low	High	Medium	High	Low
Certainty	**NEGLECT** Does ESS know if there any existing legislative controls and are they effective? (Scotland and UK)	High	Low	Low	Low	Medium	Low	High	Low	Low	Low	High	Low
Added value	**ADDED VALUE** Can ESS add value?	Medium	Medium	Low	Medium	Low	Medium	Low	Medium	High	Medium	Low	Medium
	How does Scotland compare to other nations? (High = better, Low = worse)	Medium	High	High	Low	High	Low	High	Low	Medium	High	High	High
Certainty	How confident or certain are we about ESS' knowledge of the topic?	Low	Low	Low	Medium	Medium	Medium	High	Medium	Medium	Medium	High	Medium
	Risk category	Medium	High	Medium	High	Medium	High	Low	High	Medium	Medium	Low	Medium

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