Materials to Land Assessment - Sustainability, Availability and Location.

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Executive Summary

This report examines whether there is sufficient landbank now and in the future for the safe, sustainable and beneficial use of all organic and inorganic bulky wastes and products produced in Scotland. A detailed assessment of inorganic fertilisers was not conducted as part of this project. Thirteen key groups of (mainly organic) materials have been identified and their use in agriculture, forestry, amenity and land restoration is considered.

Factors affecting the application of materials to land and their importance

Twenty factors affecting the application of materials to land are considered. These include physical, land management, seasonal, climatic and economic factors, along with regulations and good practice guidance. Compliance with some of the controls is compulsory in some or all cases (e.g. under the Nitrate Vulnerable Zones Regulations, Controlled Activities Regulations, Sludge [Use in Agriculture] Regulations and Waste Management Licensing Regulations).

Some of the factors represent major controls over spreading in one or more land uses in that they have a significant impact on the landbank for one or more materials, whereas others have relatively minor impacts. Of the factors affecting (or potentially affecting) the application of materials to land, land capability, which is linked to topography, climate, altitude, slope and soil properties, is probably the most important: 51% (4,000,000 ha) of Scotland's land area is in LCA class 6.1 or above, which effectively means that the land will have little or no requirement for applied materials. The ways in which most of the other factors studied impact on spreading depend to some extent on the relevant legislation (and associated good practice guidance), which generally aim to reduce risk. GIS datasets relating to factors under study have been prepared, where possible, to help SEPA staff to assess the impact of each one geographically.

Agricultural and non-agricultural materials that could be applied to land

Of the thirteen broad types of materials considered in the project, animal manures and slurries are by far the most important, making up around 87% of the total tonnage of materials applied in Scotland (note that this figure does not include manures deposited by grazing livestock). Even if livestock numbers and distribution change, in terms of the annual tonnage applied to land, manures and slurries will undoubtedly remain more important than all the other materials added together. The next most important materials under consideration (in tonnage terms) are anaerobic digestates (5.7% of the total tonnage of all materials applied annually), wastes from distilleries and breweries (3.5%), composts (1.7%) and sewage sludge (1.7%). Tonnages of all the remaining waste types added together make up only around 0.9% of the total tonnage of all materials applied annually.

For some of the materials considered, it was possible to get accurate, recent data on the tonnages produced in Scotland, good estimates of likely future tonnages, and excellent detail on production locations. However, this was not the case for all of the materials studied. Data was excellent for sewage sludge and clean water sludge and the tonnage data was very good for animal manures and slurries. However, the forecasts for animal manures and slurries were subject to considerable uncertainty and tonnage figures for other materials were several years old and in some cases subject to error. GIS datasets showing production locations for materials have been prepared where possible, to help SEPA staff to assess the availability of landbank for these materials.

Benefits and risks

We looked at the extent to which each of the twenty factors studied maximised the benefits of land applications (of the materials under study) and minimised the risks. In broad terms, we conclude that together, all of them help significantly to maximise benefits and minimise risk, but there are some situations of concern. Judgements have been made as to whether the beneficial impact of the factor (including legislative controls) could be improved.

There is good information on the chemical and physical properties of most of the materials under consideration, particularly for the six materials which are applied to land in greatest quantities and for clean water sludge. For that reason, the benefits and risks of applying these materials are generally well understood. At present, the greatest known risks thought to be associated with use of the materials under consideration on land relate to their phosphate, readily available nitrogen and potentially toxic element content. However, there is an awareness of the potential for contaminants of emerging concern to raise questions over the suitability of some materials for land application in future. These include microplastics, antimicrobial resistant bacteria and persistent organic pollutants.

Is there sufficient landbank now and in the future for the safe, sustainable and beneficial use of all materials produced in Scotland?

If all of the materials considered as part of this project could be spread on all parts of Scotland, then there would be sufficient landbank on which to apply them. However, the high cost of transport for bulky materials, along with the fact that much of the landbank in Scotland is affected by one or more other controls on spreading means that the availability of landbank for the materials in question differs depending on geographical area.

In order to determine whether there is sufficient landbank in Scotland to beneficially take the likely volumes of materials in future with little or no risk, it is necessary to quantify the available landbank (taking into account the controls) at relatively small scales, since bulky materials tend not to travel far because of the high cost of haulage. There are currently significant gaps in the GIS datasets on landbank and these must be addressed before the potential landbank can be assessed at useful scales.

In order to better determine the volumes of materials available for land spreading in Scotland in future, we need more accurate tonnage data and more robust forecasts for the future. The GIS dataset which has been put together reflects the data which could be obtained under the terms of this project, but with additional information and further work, it could be expanded to allow it to function effectively including all of the materials being considered in this project. As it stands, there are significant gaps in the GIS datasets on tonnages of materials and production locations.

Recommendations

Recommendations which aim to ensure that the use of materials on land is sustainable, beneficial and safe over the next 20 years were made. These covered research, development and assessment work, policy changes, improved guidance documentation, advocacy and stakeholder engagement and knowledge exchange.

Project Overview

This project aims to determine whether there is sufficient landbank now and in the future for the safe, sustainable and beneficial use of all materials (including organic and inorganic bulky wastes and products, but not inorganic fertilisers) produced in Scotland.

In the context of the main question, it is important to define what we mean in terms of “landbank”, “safe”, “sustainable” and “beneficial”.

By landbank, we mean land which is available for the spreading of some or all types of materials in agriculture, forestry, amenity and brownfield land restoration.

By “safe”, we mean without causing harm to crops, wild plants, humans, animals or the environment now and in the future.

In the context of this report, “sustainable use” means that materials are being used in such a way that they can be used over the next 20 years (or longer) in the prescribed manner without causing harm of any sort. In some cases (particularly for manufactured resources, such as the annual tonnage of compost from a single organics recycling site) it can also mean that the material is used in such a way that supplies of it are not depleted unnecessarily by applying more than the minimum required to provide benefit at each locations. Conservation of finite and manufactured resources is particularly important in some stockless arable areas where alternatives to synthetic fertilisers in the form of bulky organic manures are in short supply.

In the context of this report, “beneficial use” means that materials used in such a way will result in positive impacts on soils, crops, the wider environment, humans and other animals.

This report consists of five sections:

<u>Section 1</u> details the extent to which application of materials to land is affected in four key sectors (agriculture, forestry, amenity and brownfield land) by physical, soil, land management, seasonal, climatic and economic factors and by legislative controls.

<u>Section 2</u> outlines the tonnages of different types of organic and inorganic materials produced in Scotland and, where possible, defines the places where some of these materials are produced. Future tonnage estimates are discussed with named references where possible.

<u>Section 3</u> describes the GIS datasets developed under the project. These datasets are the first stage in developing the means to assess landbank for spreading of materials at a range of scales.

<u>Section 4</u> presents key points and conclusions from the first three chapters in the report and considers the value and limitations of the work done to date. It then addresses the fundamental question from the project as a whole.

<u>Section 5</u> provides recommendations on changes required to policies, guidance and practices to ensure the use of materials on land is sustainable over the next 20 years.

1 Identification of the physical, soil, land management, seasonal, climatic and economic factors and legislative controls affecting the application of materials to land.

1.1 Introduction

There has been no previous study which has detailed and quantified the factors which affect the application of both inorganic and organic wastes, non-wastes and waste-derived products to land in Scotland. This section details the extent to which the application of these materials is affected in four key sectors (agriculture, forestry, amenity and brownfield land) by land classification, topography, land use, legislation, designations, farming rules, competition (from other materials) and costs.

For brevity, the term “bulky fertilisers and soil conditioners” is often used to describe most of the materials under consideration in this report. Materials which might fall outside of this description, because they are not bulky in relation to their fertiliser value, are included despite being typically applied at relatively small volumes (in particular waste gypsum and some types of waste ash).

Inorganic fertilisers are not included in this study. The British Survey of Fertiliser Practice provides useful estimates of average application rates for nitrogen (N), phosphate (P) and potash (K) used for agricultural crops and grassland (Defra, 2019a). This data includes summarised results for Scotland.

The factors and controls included in this study are:

1. Land Capability
2. Seasonal and climatic effects
3. Slope and topography
4. Distance from landbank for organic materials
5. Soil type and soil properties
6. Proximity to water bodies (related to slope and topography)
7. Controlled Activities Regulations (CAR) General Binding Rules (GBRs) covering diffuse pollution
8. Crop nutrient requirements (linked to land use and land management)
9. Controls on nitrogen (N) loading rates both within and outside Nitrate Vulnerable Zones (NVZs)
10. Phosphorus (P) loadings
11. Competition between different materials, particularly those from agriculture
12. Controls in the Sewage Sludge (Use in Agriculture) Regulations (1989) (including soil pH and potentially toxic element (PTE) concentrations)
13. Controls under Waste Management Licensing Exemption rules
14. Risk of pathogen transfer to food crops and water bodies
15. Controls on designated sites
16. Farm Quality Assurance Scheme rules and produce buyers rules
17. Organic Farming regulations and rules
18. Land restoration requirements for nutrients and organic matter that do not result in over-application
19. The cost of materials (financial acceptability in different sectors)
20. Carbon footprinting

These factors and controls are discussed in more detail throughout Section 1 and are summarised for easy reference and to facilitate comparison between them in Tables 1.1 to 1.19 (there is no table for carbon footprinting).

Table 1.1. The impact of land capability class on the spreading of materials in agriculture, forestry, amenity and brownfield land

Sector		Key reference(s) if any	Nature of impact
	Agriculture	Land Classification for Agriculture (LCA) system (Scotland's soils, no date[a]: https://soils.environment.gov.scot/maps/capability-maps/national-scale-land-capability-for-agriculture/)	Land is ranked into seven classes for potential productivity and cropping flexibility. Class 1 represents land with the highest potential flexibility of use, whereas class 7 land is of very limited agricultural value. Values determined by the extent to which physical characteristics of the land (soil, climate and relief) impose long term effects on its use. Broadly speaking, land in the better classes (i.e. with lower numbers) will have more requirement for organic materials (OM) and will tend to offer greater ease of spreading through fewer limitations due to topography and climate.
	Forestry	Land Classification for Forestry system (LCF) (Scotland's soils, no date[b]: https://soils.environment.gov.scot/maps/capability-maps/national-scale-land-capability-for-forestry)	Land is ranked into seven classes based on an assessment of the increasing degree of limitation imposed by physical factors (climate, windthrow, nutrients, topography, droughtiness, wetness and soil) on the growth of trees and on silvicultural practices. It is a seven-class system, with Class F1 having excellent flexibility for the growth and management of tree crops and Class F7 being unsuitable for producing tree crops. Broadly speaking, land in the lower classes (i.e. with lower numbers) MIGHT have more requirement for organic materials (OMs) due to a lack of the required nutrients for tree growth.
	Amenity	No specific references available, but those for LCA and LCF are useful.	Impacts are likely to be similar to those for agriculture or forestry, depending on the plant species present.
	Brownfield	As per amenity sites.	As above.

Table 1.2. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land due to seasonal and climatic factors

Sector	Key reference(s) if any	Nature of controls
Agriculture	*Legislation which refers (amongst other things) to seasonal and climatic factors including:* • Controlled Activities Regulations (CAR) General Binding Rules (GBRs) covering diffuse pollution (SEPA, 2019a, www.sepa.org.uk/media/34761/car_a_practical_guide.pdf); • Controls on N loading rates in NVZs (Scottish Government, 2016a) (www.gov.scot/publications/nitrate-vulnerable-zones-guidance-for-farmers/); • Controls in the Sewage Sludge (Use in Agriculture) Regulations (SI, 1989) (www.legislation.gov.uk/uksi/1989/1263/contents/made) • Controls under Waste Management License Exemption rules (SSI, 2011; 2016). (www.legislation.gov.uk/ssi/2011/228/contents/made; www.legislation.gov.uk/ssi/2016/40/pdfs/ssi_20160040_en.pdf *Good practice information which refers to seasonal and climatic factors, e.g.:* • Scottish Executive (2005) Prevention of Environmental Pollution from Agricultural Activity (PEPFAA) Code. Scottish Executive, Edinburgh. (www.gov.scot/publications/prevention-environmental-pollution-agricultural-activity-guidance/); • Defra (2018a) Code of Good Agricultural Practice for reducing ammonia emissions. www.gov.uk/government/publications/code-of-good-agricultural-practice-for-reducing-ammonia-emissions/code-of-good-agricultural-practice-cogap-for-reducing-ammonia-emissions.	Seasonal and climatic factors *should* determine whether bulky fertilisers and soil conditioners should be applied at a particular time. To ensure that they have the desired beneficial impact (in terms of agriculture or ecology) and have no detrimental impact (for example damage to soil structure, soil erosion, nutrient leaching or gaseous emissions [e.g. of ammonia or N oxides]) they should be applied when plants require the nutrients within them and when soil is in a suitable condition for vehicles to apply and if necessary cultivate them in. This means that applications should not happen in heavy or prolonged rain, when heavy rain is forecast, when the soil is waterlogged or wetter than its workable range, when the soil is frozen or snow-covered or when prolonged cold or wet weather is likely. In addition, applications of high readily available N (RAN) materials should not happen when there is no crop demand for nutrients (i.e. during predicted periods of cold wet weather in the mid-winter months). In practice, bulky fertilisers and soil conditioners are sometimes applied in inappropriate soil and/or weather conditions due to ignorance, lack of suitable storage, commercial pressures, or other reasons.
Forestry	Legislation which refers to (amongst other things) seasonal and climatic factors - see information for agriculture in this table under : • CAR GBRs covering diffuse pollution. • Controls under Waste Management License Exemption rules. • Guidance in the UK Forestry Standard (Forestry Commission, 2017) (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/687147/The_UK_Forestry_Standard.pdf)	As above
Amenity	As per forestry sites	As above
Brownfield	As above. Good practice information which refers to seasonal and climatic factors: • SNIFFER (2010) *Code of Practice for the Use of Sludge, Compost and other Organic Materials for Land Reclamation*; • Defra (2005) Guidance for Successful Restoration of Mineral Waste Sites. Department for Environment Food and Rural Affairs, London. • MAFF (2000) Good Practice Guidance for Handling Soils. Ministry of Agriculture Fisheries and Food, Farming and Rural Conservation Agency, Cambridge.	As above

Table 1.3. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land due to slope and topography

Sector	Key reference(s) if any	Nature of controls
Agriculture	The CAR Regulations and practical guide (SEPA, 2019a) www.sepa.org.uk/media/34761/car_a_practical_guide.pdf www.legislation.gov.uk/ssi/2017/389/pdfs/ssi_20170389_en.pdf	General controls under GBR 18 of the Controlled Activity Regulations (CAR) that states that no fertiliser shall be applied to land that is sloping, unless the fertiliser is inorganic or it is ensured that any run-off of fertiliser is intercepted (by means of a sufficient sized buffer or otherwise) to prevent it entering any river, burn, ditch, wetland, loch, transitional water or coastal water towards which the land slopes.
Forestry	As above	Same as agriculture in terms of general regulations however there has historically been an acceptance of land spreading and incorporation for forestry applications on slopes up to 25°.
Amenity	As above	No specific controls aside from the CAR regulations.
Brownfield	As above	Site specific, aside for the CAR regulations

Table 1.4. Distance from landbank and its impact on the spreading of materials in agriculture, forestry, amenity and brownfield land

Sector	Key reference(s) if any	Nature of impact of the factor
Agriculture	WRAP (2012) (www.wrap.org.uk/sites/files/wrap/Digestates%20from%20Anaerobic%20Digestion%20A%20review%20of%20enhancement%20techniques%20and%20novel%20digestate%20products_0.pdf)	The high cost of transporting heavy organic materials prohibits long-distance transport, and most animal manures are spread on the farm of origin, therefore distance from landbank is not a major restriction on spreading for most of the total tonnage of all materials produced. However, it has become a critical issue for some sources of organic materials such as digestates and manures/slurries from intensive poultry production. While organic materials have a fertiliser value and therefore a real financial value, it tends to be low once transportation, storage and spreading costs are taken account. Scottish Water aim to spread treated sewage sludge within a ~30 km radius around treatment works (pers. comm.), but in some cases, sludges can be transported much further. For other waste-derived organic fertilisers, the economically viable distance they can be transported for land spreading can be as small as a 15 km radius from the source of origin. The use of dewatering and drying can reduce transportation cost. When distance to land base is not adequately considered then long-term storage is often a consequence which can have environmental considerations.
Forestry	No known reference available	Wastes such as sewage sludge that attract a high gate fee have historically been used for fertiliser on forestry land. Often, the key to the financial viability of these projects is a relativity high application rate which needs to be balanced with the lack of a recognised fertiliser requirement for forestry establishment.
Amenity	No reference available	Same as agriculture.
Brownfield	WRAP (2012) (www.wrap.org.uk/sites/files/wrap/Digestates%20from%20Anaerobic%20Digestion%20A%20review%20of%20enhancement%20techniques%20and%20novel%20digestate%20products_0.pdf)	This is similar to forestry in that there is usually no economic driver that justifies the cost of transport and restoration aside from the gate fees that the use of waste can generate.

Table 1.5. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land due to soil type/soil properties

Sector	Key reference(s) if any	Nature of controls
Agriculture	The CAR Regulations and practical guide (SEPA, 2019a) www.sepa.org.uk/media/34761/car_a_practical_guide.pdf www.legislation.gov.uk/ssi/2017/389/pdfs/ssi_20170389_en.pdf Soils risk maps (Scotland's soils, no date[c]), https://soils.environment.gov.scot/maps/risk-maps/	The only specific controls relating to soil type exist for shallow soil under the Controlled Activities Regulations, which state that no organic fertiliser shall be applied to land that "has an average soil depth of less than 40 centimetres and overlies gravel or fissured rock, except where the application is for forestry operations." Increased risk associated with spreading to land that is prone to waterlogging and surface runoff and leaching can be found using the James Hutton "Soil runoff risk" and "Soil leaching potential" risk maps available at the link provided.
Forestry	UK Forestry Standard (Forestry Commission, 2017) (https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/687147/The_UK_Forestry_Standard.pdf)	Same as agriculture.
Amenity	The CAR Regulations and practical guide (SEPA, 2019a) www.sepa.org.uk/media/34761/car_a_practical_guide.pdf www.legislation.gov.uk/ssi/2017/389/pdfs/ssi_20170389_en.pdf	Same as agriculture.
Brownfield	As above	Same as agriculture unless permitted as an exempt activity or exempt under CAR regulations (shallow soils).

Table 1.6. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land due to proximity to water bodies (related to slope and topography)

Sector	Key reference(s) if any	Nature of controls
Agriculture	The CAR Regulations and practical guide (SEPA, 2019a) www.sepa.org.uk/media/34761/car_a_practical_guide.pdf www.legislation.gov.uk/ssi/2017/389/pdfs/ssi_20170389_en.pdf	General controls across all land use sectors apply under GBR 18 of the Controlled Activity Regulations that stipulate that "no organic fertiliser may be applied to land that is within 10 metres of any; • river, burn, ditch or loch, as measured from the top of the bank; • wetland; • transitional water or coastal water as measured from the shoreline; or • opening into any surface water drainage system; No organic fertiliser can be applied on land that is sloping, unless it is ensured that any run-off of fertiliser is intercepted (by means of a sufficient buffer zone or otherwise) to prevent it from entering any river, burn, ditch, wetland, loch, transitional water or coastal water towards which the land slopes".
Forestry	As above	As above
Amenity	As above	As above.
Brownfield	No known reference	These controls are set under terms of an exemption or permit

Table 1.7. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land due to CAR GBRs

Sector	Key reference(s) if any	Nature of controls
Agriculture	The CAR Regulations and practical guide (SEPA, 2019a) www.sepa.org.uk/media/34761/car_a_practical_guide.pdf www.legislation.gov.uk/ssi/2017/389/pdfs/ssi_20170389_en.pdf	Under the Controlled Activities Regulations, organic fertilisers shall not be applied to land that is within 10 metres of any; • river, burn, ditch or loch, as measured from the top of the bank; • wetland; • transitional water or coastal water as measured from the shoreline; or • opening into any surface water drainage system. Under the same regulation no organic fertilisers shall be applied to land; • that is sloping, unless it is ensured that any run-off of fertiliser is intercepted (by means of a sufficient buffer zone or otherwise) to prevent it from entering any river, burn, ditch, wetland, loch, transitional water or coastal water towards which the land slopes; • that "has an average soil depth of less than 40 centimetres and overlies gravel or fissured rock, except where the application is for forestry operations". Additionally, GBR 18 states that fertilisers must not be applied to land in excess of the nutrient needs of the crop.
Forestry	As above	Same as agriculture, apart from the controls on applications to land with a soil depth of < 40 cm for which forestry is exempt.
Amenity	As above	Same as agriculture.
Brownfield	As above	Same as agriculture aside from any allowance made under the exemption or permit.

Table 1.8. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land due to crop nutrient requirements (linked to land use and land management)

Sector		Key reference(s) if any	Nature of controls
	Agriculture	The CAR Regulations and practical guide (SEPA, 2019a) www.sepa.org.uk/media/34761/car_a_practical_guide.pdf www.legislation.gov.uk/ssi/2017/389/pdfs/ssi_20170389_en.pdf Farm Advisory Service Scottish Technical Notes (FAS, 2020) (www.fas.scot/publication/technical-notes/) Scottish Government guidance on cross compliance (Scottish Government, no date) (www2.gov.scot/Topics/farmingrural/Agriculture/grants/Schemes/Crosscompliancesection/ccompliance). Planet nutrient management website (PLANET, no date) (www.planet4farmers.co.uk/) Scotland's Soils website (Scotland's soils, no date[d]) https://soils.environment.gov.scot/maps/thematic-maps/map-of-soil-phosphorus-sorption-capacity/	CAR General Binding Rule18 stipulates that nutrients must not be applied in excess of crop requirements. This implies that an accessible and authoritative reference exists that defines requirements. For the purpose of this report the FAS technical fertiliser notes (FAS, 2020) are treated as the reference for requirements except where NVZ rules required additional limits. Soil testing is a key consideration when assessing the suitability for spreading of organic fertilisers to agricultural land. Phosphorus (P) is a key concern for environment protection and tools such as PLANET Scotland and MANNER can be used to make sure proposed applications are justifiable. Soil P sorption capacity maps along with the soil nutrient surplus/deficit maps can provide an indication of areas where local availably of organic material may lead to high soil test results for this critical nutrient. In Scotland, any land currently designated as rough grazing for the purposes of receiving the single farm payment cannot be fertilised. This includes all types or organic amendments such as manure, slurry and any waste derived materials.
	Forestry	The CAR Regulations and practical guide (SEPA, 2019a) www.sepa.org.uk/media/34761/car_a_practical_guide.pdf www.legislation.gov.uk/ssi/2017/389/pdfs/ssi_20170389_en.pdf	The evidence to support the need for the fertilisation of land prior to reforestation or afforestation is limited and a requirement should not be assumed.
	Amenity	As above	As with forestry the need for fertilising amenity land is limited and should not be assumed. Any sites with a specific designation (such as Sites of Special Scientific Interest, SSSI) are likely to have controls on the spreading of fertiliser but this should not be assumed.
	Brownfield	As above	Key distinctions needs be made between soil formation activities and the application of nutrients to support plant growth. These distinctions are usually made in the exemption application.

Table 1.9. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land due to N loading rates (within and outside NVZs)

Sector	Key reference(s) if any	Nature of controls
Agriculture	Controls on N loading rates in NVZs (Scottish Government, 2016a) (www.gov.scot/publications/nitrate-vulnerable-zones-guidance-for-farmers/)	NVZ controls on N use and closed periods for land spreading are important measures designed to protect groundwater quality in several regions of Scotland; • Lower Nithsdale • Lothian and Borders • Strathmore and Fife • Moray, Aberdeenshire/Banff and Buchan • Stranraer Lowlands Detailed maps of NVZ's are provided in the GIS database and are also available from the Scottish Government website (Scottish Government, 2016a). Key points include: • Controls over N use (crop-specific) • Winter closed periods for the land spreading of high N-containing organic fertilisers Within NVZs, the total amount of N that can be applied annually is limited to crop requirements as detailed in the legislation and, additionally, the total potential annual amount of total N from organic sources is limited to a maximum of 250 kg/ha excluding that deposited by animals whilst grazing. An important exception is that farmers can now apply up to 250 kg/ha of extra organic N in the form of approved compost, as long as the maximum application rate of 500 kg/ha is not breached. However the following year's applications must be planned so that over 24 months, the annual NVZ limit of 250 kg/ha of organic N is not broken.
Forestry	No references	The evidence supporting the need for N fertilisation of all forms of forestry land (standing, afforestation and reforestation) is limited and should not be assumed.
Amenity	No references	No specific controls aside from GBR 18 limits.
Brownfield	No references	All applications of fertilisers should be justified but any application of organic sources of N in excess of 250 kg/ha should be justified in detail.

Table 1.10. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land due to P loading rates

Sector	Key reference(s) if any	Nature of controls
Agriculture	Controls on N loading rates in NVZs (Scottish Government, 2016a) (www.gov.scot/publications/nitrate-vulnerable-zones-guidance-for-farmers/)	The only specific legislation that places controls on the use of P in agriculture is the requirement for those grassland farmers in NVZ who are seeking to apply N under a derogation. As part of the application to do this they must supply a P management plan. The only other control is the generalised requirement under GBR 18 that nutrients must not be applied in excess of crop requirements.
Forestry	No known reference	As with N, the specific fertiliser phosphate requirement for forestry should not be assumed.
Amenity	No known reference	No requirements beyond GBR 18.
Brownfield	No known reference	Key consideration is that the amount and source of P needs to be balanced with the availability of other key nutrients. The use of a single, high P-containing organic material without provided a source of N and potassium (K) cannot be justified.

Table 1.11. Effects on the spreading of materials in agriculture, forestry, amenity and brownfield land due to competition between different materials, particularly those from agriculture

Sector		Key reference(s) if any	Nature of effects
	Agriculture	No known references	This category includes competition within a farm which produces its own manures and may therefore be less likely to want to import other bulky organic materials. Competition for landbank is difficult to quantify, given that no two fertilisers or soil conditioners are exactly the same and because the amount of landbank within a defined number of hectares will differ markedly depending on the type of farming systems present. Competition can only be effectively assessed for individual areas based on detailed studies of available materials and local farming systems.
	Forestry and brownfield restoration	No known references	Where competition exists between different products, by-products and wastes in forestry and brownfield site restoration, the most cost-effective solution will usually be sought, so products which are available in the given area and which have the highest gate fee are likely to be chosen over those with lower gate fees, providing they can be shown to confer agricultural or ecological benefit.
	Amenity	No known references	It is not possible to summarise the types of wastes applied in amenity situations without reading the many individual certificates of agricultural benefit and waste returns supplied to SEPA in support of waste management licence exemptions (Paragraphs 8 and 9). “Off the shelf” products are mainly used, including pesticides, fertilisers and soil conditioners such as composts and animal manures. Where competition exists between different products, cost is important, but often less than quality (in terms of the formulation, ease of use, nutrient content and/or other product characteristics).

Table 1.12. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land due to the Sludge (Use in Agriculture) Regulations

Sector	Key reference(s) if any	Nature of controls
Agriculture	Statutory Instrument 1989 No. 1263. The Sludge (Use in Agriculture) Regulations (1989). (SI, 1989) (www.legislation.gov.uk/uksi/1989/1263/contents/made) BAS (2017) Biosolids Assurance Scheme – The Scheme Standard Issue 4, 13th November 2017 (https://assuredbiosolids.co.uk/wp-content/uploads/2018/04/BAS-STANDARD-Issue-4-Online-version.pdf) Scottish Executive (2005) Prevention of Environmental Pollution from Agricultural Activity (PEPFAA) Code. Scottish Executive, Edinburgh. (www.gov.scot/publications/prevention-environmental-pollution-agricultural-activity-guidance/) ADAS (2001) The Safe Sludge Matrix: Guidelines for the Application of Sewage Sludge to Agricultural Land, 3rd Edition. ADAS, Wolverhampton. www.adas.co.uk/Home/Publications/DocumentStore/tabid/211/Default.aspx	• Strictly speaking, untreated sludge is permitted under the current sludge regs. However such sludge would not meet standards in The Safe Sludge Matrix (SSM) and any farmer spreading such sludge would find it difficult or impossible to sell his / her produce. No untreated sludge has therefore been applied to UK farmland for at least the last 20 years. Many organisations, including SEPA are keen to see the rules in the SSM made legal requirements. • Treated sludges are permitted for application to growing cereals and oilseed rape. Application is also permitted to growing grass, turf and fruit trees, but harvest intervals apply. • Treated sludges are permitted for application prior to growing cereals, grass, fodder, sugar beet, oilseed rape and similar crops and fruit trees. Application is also permitted prior to sowing/planting soft fruit, potatoes, vegetables and nursery stock, but controls apply. • Sewage sludge must not be applied to soils which have pH values lower than 5.0. • Limits are in place (in terms of soil concentrations of six potentially toxic elements (PTE's) (zinc [Zn], copper [Cu], nickel [Ni], cadmium [Cd], lead [Pb] and mercury [Hg]) beyond which sludge cannot be applied for soils of pH 5.0 and above. These limits vary for different pH values for Zn, Cu and Ni and in some cases differ between grassland soils and those used for arable cropping. Recommended limits are also in place for Chromium (Cr), Molybdenum (Mo), Selenium (Se), Arsenic (As) and Fluorine (F) (Scottish Executive, 2005). • Maximum permissible average annual rates of PTE addition over a 10-year period must not be exceeded for the above eleven PTEs.
Forestry and brownfield restoration	Controls are not relevant	Not relevant
Amenity	Controls are not relevant	Not relevant

Table 1.13. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land under the Waste Management Licence Exemption Rules

Sector	Key reference(s) if any	Nature of controls
Agriculture	The Waste Management Licensing (Scotland) Regulations 2011. Scottish Statutory Instrument 2011 No. 228. (SSI, 2011; SSI, 2016) (www.legislation.gov.uk/ssi/2011/228/contents/made www.legislation.gov.uk/ssi/2016/40/pdfs/ssi_20160040_en.pdf) Applications of wastes may be undertaken on: • agricultural and non-agricultural land under exemptions from waste management licensing, via Paragraph 7 (agriculture, forests, parks etc.) (SEPA website, www.sepa.org.uk/regulations/waste/activities-exempt-from-waste-management-licensing/); SEPA, 2015a); • non-agricultural land under a Paragraph 8 (storage and spreading of sludge on non-agricultural land) or Paragraph 9(1) (remediation or restoration) (SEPA website, www.sepa.org.uk/regulations/waste/activities-exempt-from-waste-management-licensing/; SEPA, no date; SEPA, 2015a; SEPA, 2020);	In practice, the nature of any agricultural or ecological benefit must be defined and the application rate of the waste in question justified. Application rates of wastes to agricultural crops (under Paragraph 7 exemptions) are traditionally matched to the demand of a single crop or crops within a rotation. Application rates of wastes to land being restored for the purposes of non-food crop production, forestry or amenity have traditionally been much higher. For example, rates of up to 500 dry tonne/ha were typical (SNIFFER, 2010). SEPA has begun reducing the maximum permitted application rates of wastes in land restoration. Limits of no more than 2,000 kg/ha of phosphate and no more than 750 kg/ha of RAN have been set where mixtures of sewage and clean water sludges are being used in brownfield restoration. These limits have not yet been set in statute or published in the form of guidance other than in the new landfill restoration form.
Forestry	As above	As above
Amenity	As above	As above
Brownfield	As above	As above

Table 1.14. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land due to the need to minimise pathogen transfer to food and water bodies

Sector	Key reference(s) if any	Nature of controls
Agriculture	The Sludge (Use in Agriculture) Regulations 1989 (SI, 1989) (www.legislation.gov.uk/uksi/1989/1263/contents/made) BAS (2017) Biosolids Assurance Scheme – The Scheme Standard Issue 4, 13th November 2017 (https://assuredbiosolids.co.uk/wp-content/uploads/2018/04/BAS-STANDARD-Issue-4-Online-version.pdf) Scottish Executive (2005) Prevention of Environmental Pollution from Agricultural Activity (PEPFAA) Code. (www.gov.scot/publications/prevention-environmental-pollution-agricultural-activity-guidance/) Main assurance schemes operational in Scotland include: • Quality Meat Scotland (www.qmscotland.co.uk/) • Scottish Quality Crops (www.sqcrops.co.uk/) • Assured Food Standards (Red Tractor) (https://assurance.redtractor.org.uk/) • LEAF (https://leafuk.org/) PAS100 and the UK Compost Quality Certification Scheme (www.qualitycompost.org.uk/). BSI (2018) PAS 110 and the UK Biofertiliser Certification Scheme (www.biofertiliser.org.uk/). BSI (2014) The Animal By-Products Regulations (SSI, 2013) Scottish Statutory Instruments (2013) The Animal By-Products (Enforcement) (Scotland) Regulations 2013. Statutory Instrument 201 No. 307). (www.legislation.gov.uk/ssi/2013/307/introduction). The Safe Sludge Matrix: Guidelines for the Application of Sewage Sludge to Agricultural Land, 3rd Edition. ADAS, Wolverhampton. www.adas.co.uk/Home/Publications/DocumentStore/tabid/211/Default.aspx ADAS (2001)	Controls which minimise the risk of pathogen transfer include those set out in the Sludge (Use in Agriculture) Regulations (1989) (in relation to non-spreading buffer zones), the Safe Sludge Matrix, the CAR (GBR 18) and those set out for different crop types in the various farm assurance schemes. The assurance scheme rules are least strict for non-edible crops and most strict where crops can potentially be eaten raw. There are pathogen limits (*E. coli* and *Salmonella* species) in PAS 100 composts and PAS 110 digestates. There are controls with respect to the treatment and subsequent use of animal by-products on land.
Forestry	The CAR Regulations and practical guide (SEPA, 2019a) www.sepa.org.uk/media/34761/car_a_practical_guide.pdf www.legislation.gov.uk/ssi/2017/389/pdfs/ssi_20170389_en.pdf	Controls which minimise the risk of pathogen transfer include those set out in the CAR (GBR 18).
Amenity	As per forestry sites	As above.
Brownfield	As per forestry sites	As above.

Table 1.15. Controls on the spreading of materials in agriculture, forestry, amenity and brownfield land on designated sites

Sector	Key reference(s) if any	Nature of controls
Agriculture	Scottish Natural Heritage (SNH) has power to regulate SSSIs in terms of: • the Wildlife and Countryside Act 1981 (www.legislation.gov.uk/ukpga/1981/69/schedule/9) and • the Nature Conservation (Scotland) Act 2004 (www.legislation.gov.uk/asp/2004/6/contents) SNH (2011) Sites of Special Scientific Interest (www.nature.scot/sites/default/files/2017-06/Publication%202011%20-%20Sites%20of%20Special%20Scientific%20Interest.pdf) Owners of SSSIs should hold a Schedule of Operations requiring the consent of SNH in relation to that land. In most cases they will be unable to apply organic materials to the land due to the risk of them changing fundamentally important aspects of the habitat or ecosystem on the site.	For the purposes of this report, designated sites include Sites of Special Scientific Interest (SSSIs), Special Protection Areas (SPAs), Special Areas of Conservation (SACs), Ramsar wetland sites, National and Local Nature Reserves, sites listed in the “Inventory of gardens and Designed Landscapes”, National Scenic Areas, National Parks and Regional Parks. Other than controls imposed by SNH, and relevant legal and other controls listed elsewhere in this table, specific controls on designated sites are likely to be bespoke and will relate to protection of the habitats and species present on them. The Natural Heritage Designated Areas of Scotland are detailed in Scottish Government (2007).
Forestry	As above	As above
Amenity	As above	As above
Brownfield	As above	As above

Table 1.16. Controls on the spreading of materials in agriculture and forestry due to farm assurance scheme and produce buyer rules

Sector	Key reference(s) if any	Nature of controls
Agriculture	Main assurance schemes operational in Scotland include: • Quality Meat Scotland (QMS 2017a; b) (www.qmscotland.co.uk/) • Scottish Quality Crops (SQC, 2018) (www.sqcrops.co.uk/) • Assured Food Standards (Red Tractor Assurance, 2018) (https://assurance.redtractor.org.uk/) • LEAF (LEAF, 2016) (https://leafuk.org/)	Rules vary depending on assurance schemes. Some, e.g. the two main Scottish schemes (QMS and SQC) prohibit use of named materials (e.g. untreated sewage sludges and off-specification composts and digestates). Some produce assurance schemes are effectively private, unpublished and available to licensees only. Many produce buyers have unwritten rules that farmers must comply with. Almost all assurance schemes require farmers to prove compliance with legislation and good agricultural and environmental practice in relation to use of organic fertilisers and soil conditioners.
Forestry	The UK Woodland Assurance standard (UKWAS) is an independent certification standard for verifying sustainable woodland management in the UK. The UK Forestry Standard (UKFS) is the reference standard for sustainable forest management across the UK.	Recommendations and rules relating to the use of organic materials in woodland are given. For example, attention is drawn to the relevant parts of the CAR Regs. and managers of woodland in NVZs are recommended to follow NVZ rules in relation to N applications.
Amenity	Not relevant	Not relevant
Brownfield	Not relevant	Not relevant

Table 1.17. Controls on the spreading of materials in agriculture due to organic farming regulations and rules

Sector	Key reference(s) if any	Nature of controls
Agriculture	EU organic regulation (https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2018.150.01.0001.01.ENG) Organic certification body websites: • Scottish Organic Producers Association (SOPA, www.sopa.org.uk/) • Soil Association (www.soilassociation.org/certification/?gclid=EAIaIQobChMIopiR__zC4gIVz7ztCh1bNwNNEAAYASAAEgLJTvD_BwE) • Organic Food Federation (www.orgfoodfed.com/) • Organic Farmers and Growers (https://ofgorganic.org/) Biodynamic Agricultural Association (http://bdcertification.org.uk/index.php/bd-certification/)	There are prohibitions on all synthetic fertilisers and manures from intensive livestock systems and controls on the type and amount of off-farm wastes and products used. All fertiliser applications must be based on a proven need for the nutrients concerned. In summary, no off-farm inputs of nutrients or organic matter are permitted unless soil test results prove the need. No material which might contain any genetically modified material will be permitted. If a farmer wishes to use an organic or inorganic waste, then he must submit a detailed lab analysis of its properties along with an account of its origin and test results from the farm soil to his chosen certification body, which will make a decision as to whether the material can be used on the farm.
Forestry	Not relevant	Not relevant
Amenity	Not relevant	Not relevant
Brownfield	Not relevant	Not relevant

Table 1.18. Controls on the spreading of non-waste materials to brownfield land

Sector	Key reference(s) if any	Nature of controls
Agriculture	Not relevant	Not relevant
Forestry	Not relevant	Not relevant
Amenity	Not relevant	Not relevant
Brownfield	Sniffer (2010); SEPA (2018a) and information gained from experience in the land restoration sector.	It would in theory be possible to over-apply non-waste bulky organic materials such as PAS 100 composts and animal manures on restoration sites, thus creating environmental problems. However, due to the high cost of non-waste fertilisers and soil conditioners, materials applied to restore and improve soils in land restoration are almost exclusively wastes and sewage sludges, i.e. those which attract a gate fee. Application controls are covered under Sections 1.2.12 and 1.2.13.

Table 1.19. Effects on the spreading of materials in agriculture, forestry, amenity and brownfield land due to cost of materials

Sector	Key reference(s) if any	Nature of effects
Agriculture	No known references	Farmers are generally keen to save money on their fertiliser bill and are prepared to pay for bulky organic and other waste fertilisers if the quality is appropriate and the cost is lower than that of equivalent synthetic fertilisers. Some, particularly organic farmers and those with concerns over soil quality may pay a little more (than for synthetic fertiliser nutrients) for bulky organic fertilisers with soil conditioning properties.
Forestry	No known references	The economics of forestry, land remediation and restoration are such that forest managers usually require to be paid to take waste fertilisers and soil conditioners (via gate fees). They are almost never prepared to pay for them. Where they are attempting to improve soils, loading rates are limited primarily by the P content of the waste, but also sometimes RAN and PTE content.
Amenity	No known references.	The amenity market is relatively small, but some in this sector (e.g. landscapers and golf course managers) are prepared to pay a great deal more than farmers for materials that they perceive to have good qualities. They tend to have very low tolerance for odorous products or those with visible physical contaminants though.
Brownfield	SEPA (2018a)	See Forestry

1.2 Identify and quantify the physical, land, soil, land management, seasonal and climatic factors and legislative controls affecting the application of organic materials to land.

1.2.1 Land capability

Agriculture: The Land Capability for Agriculture (LCA) system is the official agricultural classification system widely used in Scotland by agriculturalists, planners, estate agents and others as a basis of land valuation (www.hutton.ac.uk/learning/exploringscotland/land-capability-agriculture-scotland). It is used to rank land on the basis of its potential productivity and cropping flexibility and is determined by the extent to which the physical characteristics of the land (soil, climate and relief) impose long term controls on its use. It is a seven class system. Four of the classes are further subdivided into divisions. Class 1 represents land that has the highest potential flexibility of use whereas Class 7 land is of very limited agricultural value. The LCA classification is applied through a series of guidelines that allows a high degree of consistency of classification between users. The classification is based upon a number of assumptions. These specifically include the potential flexibility of cropping and agricultural options, assuming a high level of management. The LCA system excludes factors such as distance to market and the choices of land managers, which all of which can influence land use and therefore the potential for using imported inorganic and organic materials. Broadly speaking, the greater the land capability, the greater the opportunity for applying imported organic materials, given that more nutrient-demanding crops tend to be grown in land with a greater capability. For example, a wheat crop grown in grade 1 agricultural land will require relatively high inputs of lime and nutrients annually and the topography of typical class 1 agricultural land will usually be suitable for easy application. On the other hand, rough grazing will generally require little or no annual inputs and the topography of such land often makes applications difficult or impossible.

Forestry: The Land Capability for Forestry classification (LCF) aims to present detailed information on soil, climate and relief in a form which will be of value to land use planners, foresters, consultants and land managers (www.hutton.ac.uk/learning/natural-resource-datasets/landcover/land-capability-forestry). The classification is based on an assessment of the increasing degree of limitation imposed by seven physical factors (including climate, windthrow, nutrients, topography, droughtiness, wetness and soil) on the growth of trees and on silvicultural practices. It is a seven class system, with Class F1 having excellent flexibility for the growth and management of tree crops, Class F6 having very limited flexibility for this and Class F7 being unsuitable for producing tree crops.

The system is designed for use at several levels depending on the amount and accuracy of the available data and on the purpose for which the information is required. It is an interpretation derived from several sources and, as with all such approaches, will be subject to some degree of arbitrary decision. Broadly speaking, the more nutrient poor the land, or the more depleted it is in organic matter, potentially the greater the opportunity for applying imported organic materials. For example, trees planted in land with a high capability for forestry have the potential for high productivity based on the natural ability of the land to support trees. On the other hand, trees grown on land with a low capability for forestry due to a lack of nutrients may have a higher requirement for applied nutrients. Further detail on this is provided in Rollet *et al.*, (2015).

Amenity: The Land Capability Classifications for Agriculture and Forestry (LCA and LCF) were not designed for use with amenity land and there is no equivalent classification for amenity land. However, given that the values ascribed under both systems are based on assessment of the increasing degree of limitation imposed by the physical factors of soil, topography and climate, in fact LCA and LCF are both useful for buyers, planners and managers of amenity land, with the relative usefulness of each system depending on the plant species present or planned. Some end uses will entail a much greater need for nutrients than others. For example, a golf course, where there is a requirement for the development and growth of a robust grass sward will require higher levels of nutrients than a wild flower meadow or a community woodland with native trees.

Brownfield: The amount and location of brownfield land which is currently classed as vacant or derelict is assessed annually in Scotland in the Scottish Vacant and Derelict Land Survey (Scottish Government, 2020). In 2019 (the latest data) there was 10,926 ha of derelict or urban vacant land in Scotland.

The Land Capability Classifications for Agriculture and Forestry (LCA and LCF) were not designed for use with brownfield land intended for restoration, and there is no equivalent classification for brownfield land. If a LCA classification were required for a newly restored brownfield site, then the land would have to be reassessed and a new value allocated as appropriate. The new value may end up being very different from the original value for that same land pre-industrial development.

LCA is included in the GIS data set (Section 3.5) as layer data set that classifies each class into one of 3 risk classes. Further details are provided in Section 3.5.

1.2.2 Seasonal and climatic factors

Seasonal and climatic factors *should* determine whether bulky fertilisers and soil conditioners should be applied at a particular time. In order to ensure that they have the desired beneficial impact (in terms of agriculture or ecology) and have no detrimental impact (for example damage to soil structure, soil erosion, nutrient leaching or gaseous emissions [e.g. of ammonia or nitrous oxides]) they should be applied when the plants require the nutrients within them and when the soil is in a suitable condition for vehicles to apply and if necessary cultivate them in.

The PEPFAA code states that liquid organic materials such as slurries and liquid digestates should not be applied in heavy or prolonged rain, when heavy rain is forecast, when the soil is waterlogged or wetter than its workable range, when the soil is frozen or snow-covered or when prolonged cold or wet weather is likely (Scottish Executive, 2005). Although the PEPFAA code does not give timescales, new guidance being prepared by SAC Consulting will recommend that no spreading of liquid manures takes place if heavy rainfall is forecast within 12 hours. Although it is widely acknowledged that nutrient leaching is much less from solid organic materials than liquids, best practice would be to refrain from spreading all types of organic materials in the above-mentioned conditions (SRUC, 2019). In addition, applications of high readily available nitrogen (RAN) materials should not happen when there is no crop demand for nutrients (i.e. during predicted periods of cold wet weather in the mid-winter months). High RAN materials are defined as containing > 30% ammonium, nitrate and/or uric acid N. Good agricultural practice, which defines how to maximise the benefit from bulky materials and minimise the detrimental impact of applications is widely promoted in a range of publications including the PEPFAA code (Scottish Executive, 2005), the Code of Good Agricultural Practice for reducing ammonia emissions (Defra, 2018a), in Sewage Sludge in Agriculture: Code of Practice for England, Wales and Northern Ireland (Defra, 2018b) and elsewhere. Good practice in land restoration is also covered in SNIFFER (2010). However, farmers often lack sufficient storage space for liquid manures, AD Plants, including those based at distilleries, often lack sufficient storage space for digestates during wet weather and the lure of gate fees is often sufficiently tempting for both farmers and land restoration companies to consider applying waste bulky organic fertilisers and soil conditioners almost regardless of the weather.

Scotland has always had a wet maritime climate, but many farmers and restoration companies claim that they are suffering increasingly from difficulties in applying bulky fertilisers and soil conditioners due to changes in rainfall patterns attributed to climate change. There is general acknowledgement amongst UK meteorologists that the UK is experiencing an increased frequency of storms and heavy rainfall events.

Legislation goes a long way in preventing application of bulky fertilisers and soil conditioners in cold or wet conditions or to wet soils in some instances. For example, the NVZ regulations apply to about 10% of the agricultural area in Scotland (Section 1.2.9). The Controlled Activities Regulations give protection to all land used for agriculture, forestry and amenity, as well as brownfield land (Section 1.2.7). All land to which waste materials are applied under exemptions from the Waste Management Licensing Regulations (Paragraphs 7, 8[2] and 9) is protected to some extent too (Section 1.2.13). However, there is a clear need for additional guidance, practitioner training, investment in improved equipment, machinery and storage. Further legislation may possibly be required if damage to soils, watercourses and the wider environment in wet and/cold weather is to be minimised across Scotland.

Currently the only means of mapping seasonal and climatic factors is indirectly by considering NVZ designations (Section 3.7) which includes closed periods during which there is higher risk, due to climate of leaching and runoff of applied N and nutrients and by the risk classifications applied to the LCA data set (Section 3.5).

1.2.3 Slope and topography

All land uses: Although there are general controls on spreading fertilisers and organic materials on sloping land (e.g. under the Controlled Activities Regulations) and good agricultural practice recommendations relating to steep ground (PEPFAA Code; Scottish Executive, 2005), there are also practical controls associated with the safety, cost and feasibility of spreading organic materials on steep slopes and very uneven ground. In practice, few land managers would wish to spread anything other than essential fertiliser nutrients on slopes greater than 20 degrees. Ordnance survey maps show contour lines on a range of useful scales including 1:50,000, 1:25,000, 1:10,000 and larger. These are available for all of Scotland but exclude areas used or formerly used for opencast mining, whether restored or not. Accurate landform maps for brownfield land which has or has not been restored are rarely publicly available and may not exist at all.

Slope and topography are contributing factors to both LCA and LCF and there will be overlap between areas deemed unsuitable for spreading based on slope and topography and LCA and/or LCF. LCA and LCF does not distinguish between slope and other factors such as drainage and soil depth which also impact LCA so a study of its impact on spreading based on slope are therefore not independent.

Slope and topography are included in the data set as separate layers showing areas nationally that have a slope > 15^{o} and separately those with a slope > 25^{o} (Section 3.2; Figures 7.3 and 7.4 Appendix A).

1.2.4 Distance from landbank for organic materials

The locations where organic and inorganic materials destined for land spreading arise are important, since commercial pressures limit the distance they can be cost effectively transported prior to storage and spreading.

This is a frequently ignored element of the planning process, but it is becoming a more recognised consideration. Requirements for manure management plans as part of the planning permission process for intensive livestock development are becoming standard but for other types of material such as digestate are seldom considered.

Secondary treatment such as dewatering and drying can be employed to decrease transporting and storage costs but these can be expensive and energy intensive.

As the economic and compliance drivers behind acceptable transportation costs will vary over time the focus in this study was on the mapping and characterization of the point sources where organic materials are arising (Section 3.4).

1.2.5 Soil type and soil properties

The only nationwide controls relating to soil type are for shallow soils under the Controlled Activity Regulations which state that no organic fertiliser shall be applied to land that “has an average soil depth of less than 40 centimetres and overlies gravel or fissured rock, except where the application is for forestry operations”.

Localised controls for NVZs also consider soil type by varying the closed period when organics cannot be spread. On sandy or shallow soils, the closed period starts earlier in the year (August or September) to reflect the increased risk of leaching that can occur on these soil types from organic spreading in the autumn. The closed periods for other soil types starts a month later but is extended to later in the winter to reflect the higher runoff risk they pose as compared to sandy soils.

Increased risk associated with spreading to land that is prone to waterlogging and surface runoff and leaching risk can be found using the James Hutton “Soil runoff risk” and “Soil leaching potential” datasets (for links, see Table 3.5). Both datasets have been included in this project (Section 3.6), but they only cover the major agricultural regions of Scotland. LCA also includes these factors, but as with slope, it is important to isolate them to better understanding any impact on the land to accept organic fertilisers.

1.2.6 Proximity to water bodies (related to slope, topography and land management)

This refers to the concept of connectivity between land spreading activities, landform, other land management factors and associated water bodies. There is currently no working approach to modelling all these factors. At the farm level in Scotland, this is managed through the creation of RAMS (Risk Assessment for Manure and Slurry) map that can take some of these factors into consideration.

Some work on this is currently being carried out as a research project at SRUC with the objective of creating an automated RAMS map. The RAMS work is due to be completed in 2021 and therefore has not progressed to a point where it can be included in this work.

The main factors that can currently be mapped are the legally binding buffer strips that must be established around water features and cannot be spread to. Buffer strips are established to reduce the risk of direct runoff of applied organic fertilisers into water bodies. Other factors such as slope, soil type and drainage capacity can be mapped but currently there is no construct to bring them together into a comprehensive model.

1.2.7 CAR GBRs covering diffuse pollution

Controls exist under the General Binding Rule 18 (GBR 18) of the Controlled Activity Regulations that state that organic fertilisers shall not be applied to land that is within 10 metres of any;

- river, burn, ditch or loch, as measured from the top of the bank;
- wetland;
- transitional water or coastal water as measured from the shoreline; or
- opening into any surface water drainage system

Under the same regulation no organic fertilisers shall be applied to land:

- that is sloping, unless it is ensured that any run-off of fertiliser is intercepted (by means of a sufficient buffer zone or otherwise) to prevent it from entering any river, burn, ditch, wetland, loch, transitional water or coastal water towards which the land slopes;
- that has an average soil depth of less than 40 centimetres and overlies gravel or fissured rock, except where the application is for forestry operations;

Additionally GBR 18 states that fertilisers must not be applied to land in excess of the nutrient needs of the crop.

A practical guide has been published for land managers (SEPA, 2019a). All water bodies have been mapped and a 10 m buffer applies as part of the GIS data set (Section 3.1). Soil texture and the occurrence of “shallow soils” are also provided in the data set but these only cover areas designated under the Nitrates Directive (Section 3.7).

1.2.8 Crop nutrient requirements (linked to land use and land management)

To understand crop nutrient dynamics the work by Leinonen, *et al*., (2019) was incorporated. This work provides a mechanism to understand nutrient dynamics at a national scale based on the 2015 agricultural survey (Scottish Government, 2015). Their model takes into account;

- Actual fertiliser usage (both manufactured and all organic sources)
- Fertiliser requirements
- Total livestock manure nutrient availability

As it is based on the Agricultural Census Data the resolution is limited to 2 km^2, however this is sufficient to identify;

- Crop requirements across Scotland
- Areas of greatest crop demand and those areas where local sources of livestock manures are insufficient to meet the demand.
- Net demand or surplus once livestock manure availability has been accounted for.

General Binding Rule 18 stipulates that nutrients cannot be applied in excess of crop requirements, but aside from those provided directly in the NVZ regulations there are no statutory requirements that clearly limit fertiliser application rates.

As discussed above the approach taken in this study is to estimate “actual” fertiliser usage rather than estimating potential fertiliser usage based on the biological potential of the crop (maximum potential yield).

Based on the experience of the authors, most farmers and agronomists in Scotland tend to apply less fertiliser from manufactured sources than most publicly available advice would recommend. This is generally because much of the standardised fertiliser advice is historical and based on obtaining yields that are not possible in some parts of Scotland due to the climate.

The concern is that nutrients supplied from organic sources are not, in many cases, fully accounted for in the nutrient plan leading to localised (field level) and seasonal overloading of nutrients. An unreleased report (SEPA 2018b) showed the results of a soil survey conducted in 2013 on two Scottish catchments where all agricultural soils were tested for plant-available nutrients. In general, the study concluded that key nutrients such as soil test P was either “on target” (M+ based on SAC system) or below.

Table 1.20. Summary of soil phosphate test results for two catchments (SEPA, 2018b)

	Water of Coyle		East Pow	
P Status	**Area (ha)**	**Area (%)**	**Area (ha)**	**Area (%)**
Very high (VH)	1	0.0	0	0.0
High (H)	245	5.5	329	9.8
Moderate + (M+)	812	18.2	788	23.5
Moderate – (M-)	2,387	53.6	1,726	51.4
Low (L)	957	21.5	492	14.7
Very low (VL)	52	1.2	21	0.6
Total	**4,454**		**3,356**	

As shown in Table 1.20, the percentage of soils with soil test P results higher than M+ is between 5 and 10 % with primary crop type (grass in the Water of Coyle and arable in East Pow) being a key factor on whether a field is on target for soil test P. However, the same study also noted that soil pH in some fields was below optimum for primary crop growth in both catchments. This may mean that crop P use efficiency was lower than expected due to restrictions on growth caused by below optimum soil pH. Therefore with soil P levels generally being “on target”, P may still be being lost from soils in these catchments to watercourses and that soil amendments with bulky fertilisers may be less effective than expected at supporting crop growth.

A review was conducted for the recently updated Farm Advisory Service Fertiliser Technical Note Series on P (FAS, 2019) and provides a national assessment based on soil analysis results from SRUC analytical labs (Table 1.21). This is the best national dataset available for soil test P in Scotland, although it should be noted that it is not derived from a systematic survey of Scotland’s soils. Instead, it is derived from samples submitted by farmers for testing to SRUC, which could mean that results are biased towards those fields where farmers think there may be a problem with soil P levels that is having a negative impact on crop yields. This could mean that fields with low P levels are disproportionately reported in the dataset. While not comprehensive, the review found that for soil test P that the majority of Scottish Soils were on or below a target of M+ and that the number of soils at or above this target is decreasing but these results have not been analysed statistically.

Table 1.21. Percentage (%) of samples in each SRUC P status range (FAS, 2019).

		% of the total samples in the period					
Years	**Total no. of samples**	**VL**	**L**	**M-**	**M+**	**H**	**VH**
1993 - 1997	13,209	9	29	37	13	10	2
1998 - 2002	10,528	9	27	37	12	11	2
2003 - 2007	5,900	7	27	37	14	13	3
2008 - 2012	9,938	7	28	38	14	11	2
2013 - 2017	10,456	6	32	41	12	8	1

To provide a spatial understanding of crop nutrient demand across Scotland the model developed by Leinonen *et al.* (2019) was applied nationally. Details of the model are provided in Section 3.3 but in general it uses a number of inputs to determine "actual" nutrient management practices. Crop type and the application of nutrients from livestock manures and slurries are accounted for and the net requirement (or lack of) for bagged fertiliser and/or imported organic fertilisers is estimated.

1.2.9 Controls on N loading rates both within and outside NVZs

Scotland has designated areas where agricultural use of N has been identified as posing a risk to ground water quality. Within NVZs, farmers have specific controls on the amount and timing of N applications. These areas have been included in the GIS data set (Section 3.7) as the regulations include controls on total amount of N, from both manufactured and organic sources, that can be applied, as well as controls on when they can be applied (closed periods, Table 1.22).

Within NVZs, the total amount of available N, from both organic and manufactured sources, that can be applied to crops and grass is limited to the calculated crop requirements, as detailed in the legislation. Additionally, there are field application limits for the total nitrogen that can be applied in the form of organic manures:

- 250 kg N/ha field application limit for organic nitrogen - This rule sets a field limit of 250 kg/ha of total N from all organic manures, other than compost, that are applied to land in any 12 month period, excluding grazing deposition and nitrogen applied as manufactured nitrogen fertiliser.
- 500 kg N/ha field application limit for compost - This rule sets a field limit restriction for the application of compost to 500 kg/ha of total N from all organic manures (including compost) that are applied to land in any 24 month period, excluding grazing deposition and nitrogen applied as manufactured nitrogen fertiliser.

Farmers within NVZs have a statutory requirement to maintain records of N, and in some cases P soil analysis results (when a derogation is granted) and must calculate the amount applied from organic sources using specific reference values.

NVZ regulations do not present any controls on the potential to spread different types of imported organic materials but they must be included in the NVZ N budget and must not result in the crop N requirement being exceeded.

Table 1.22. Closed periods for spreading high readily available-N organic materials to land (Scottish Government, 2019).

<table>
<tr><td rowspan="4">“Organic manure with a high available N content” means > 30% of the total N content of the organic manure is present in molecular forms that will be released in the year in which it is spread on land. This includes slurry, poultry manures and some organic wastes such as liquid digested sewage sludge.</td><td colspan="3">Closed period: no-spread within the NVZ during the following periods</td></tr>
<tr><td></td><td>Grassland</td><td>Other land</td></tr>
<tr><td>Sandy or shallow soil
All other soils</td><td>1 Sept. to 31st Dec.
15th Oct. to 31st Jan.</td><td>1st Aug. to 31st Dec.*
1st Oct. to 31st Jan.</td></tr>
<tr><td colspan="3">*Applications permitted up to and including 15th Sept., if a cereal crop is sown before that date, also permitted up to 30th Sept. if the land is sown with oilseed rape, a catch crop or cover crop before that date.
• Quantitative restrictions apply during the 4 weeks prior to the commencement of the relevant closed period and from the day following the last day of the closed period until 14th Feb.
• If applied to bare ground during July, Aug. or Sept., crop must be sown within 6 weeks of first application.
• For other rules that apply, see definitions (1) and (3) in Scottish Government (2019).</td></tr>
</table>

Across the rest of Scotland, it is recommended in the PEPFAA code (Scottish Executive, 2005) that the total amount of N from organic manures is restricted to no more than 250 kg/ha in any field over any 12-month period. For paragraph 7 Waste Management Licensing Exemptions, which cover waste materials spread on agricultural land, a limit of 250 kg/ha of total N (from the waste) can be spread over a 12-month period (note that the regulator has no control over N applied in fertilisers or other non-waste materials). Where former opencast sites, quarries and other abandoned industrial land is being restored under a paragraph 9 Waste Management Licensing Exemption, SEPA generally allow higher N addition rates, up to 750 kg/ha RAN.

Those areas currently designated under the Nitrates directive are included in the GIS data set (Section 3.7) and net N requirement (based on crop type and after N supply from Manure and slurries is accounted for) is included in Section 3.3.

1.2.10 P loadings

There are no regulatory limits on the application of P, other than the generalised requirements of General Binding Rule 18 and the Sludge (Use in Agriculture) Regulations which state that the sludge shall be used in such a way that account is taken of the nutrient needs of the plants, and that the quality of the soil, and of the surface and ground water is not impaired.

The Biosolids Assurance Scheme has interpreted the requirements of GBR 18 and Sludge (Use in Agriculture) Regulations as allowing P applications at rates that take into consideration crop requirements over several years (BAS, 2019). This means that total P loading rates in a given year from sewage sludge applications can be based on a rate that encompass the crop requirement over several cropping cycles (i.e. crop rotation).

Under paragraph 7 waste management licensing exemptions it is generally understood that any receiving land that has a soil P test result in the ‘high’ status range or higher (based on SAC methods), or index 3 range or higher (based on ADAS methods) does not require P and therefore is not suitable for land spreading of organic wastes, unless it can be demonstrated that the waste spreading will not further increase soil extractable P and there is evidence the application will have other benefits, unrelated to the P content of the waste, e.g. it has a liming effect. An exception to this may be considered for land where crops that have a high demand for available P are being grown (e.g. potatoes), but this circumstance is relatively unusual. Land that has a soil P test result in the SAC 'very high' or ADAS 4 (or above) index range is considered unsuitable for land spreading of organic wastes unless the waste to be spread supplies very little P.

The SRUC technical note TN668 Managing Soil Phosphorus (SRUC, 2015) provides an innovative approach to agricultural management of P that takes account of soil characteristics to provide more accurate fertiliser recommendations. As part of this development, all of Scotland's soils have been classified into one of three phosphorus sorption capacity (PSC) classifications (Scotland's Soils, no date[c]). Those soils with a PSC of 1 have a lower capacity to "store" P, which increases the potential for leaching if P is over applied. Soils with a PSC of 3 have the highest potential for storing P and it takes more fertiliser in order to raise soil test P levels. Due to the higher amount of P stored in these soils there is a greater risk to the wider environment if erosion occurs.

Net P requirement (based on crop type and after P supply from Manure and slurries is accounted for) is included in GIS as a separate data layer (Section 3.3.).

1.2.11 Competition between different materials

Competition for landbank will only be an issue where two or more similar bulky fertilisers or soil conditioners are available to land managers in a given geographical area. It is difficult to assess in broad terms, given that no two fertilisers or soil conditioners are exactly the same.

No references have been found which provide guidance on assessment of competition for landbank between different materials in broad terms. The degree of competition between different materials can only be quantified based on defined geographical areas and the materials available in them, since the characteristics of each area will differ in terms of the farming enterprises present, the requirements for fertiliser nutrients and organic matter and the prices which farmers are willing to pay.

The difficulty of assessing competition may be part of the reason why several organisations and private companies undertaking assessments of the amount of agricultural landbank available for their product(s) or waste(s) have failed to take into account the landbank required for current or future tonnages of other locally available materials. For example, a study to determine landbank for anaerobic digestate from a proposed (now built) AD plant near Edinburgh, looked only at the local farmland and cropping enterprises (Zero Waste Scotland, 2011). It did not assess the output tonnages of other similar materials being produced locally and the impact which their use may have on landbank for the AD plant's products. Individual operators of any proposed new facility producing bulky wastes, by-products or products are advised to conduct detailed, bespoke landbank appraisals prior to going ahead with the financing/building stages. These should consider the existence of both existing and potential sources of competing materials as well as the local landbank. To date, few such appraisals have been conducted prior to plants being built and such appraisals are not required as part of planning applications. Several UK AD plants (for example) have had, and continue to have, severe difficulties in finding financially acceptable local markets for their products.

As a general rule, the economically feasible agricultural landbank for organic matter-rich soil conditioners such as composts, fibre digestates and solid animal manures would be concentrated in mixed farming areas (where animal manures are often applied on the farm of origin) and arable areas (where many soils have become depleted in organic matter) within a 20 to 30 mile radius of production. The maximum distance to which materials can be transported depends on the haulage cost, which in turn depends on fuel costs, the extent to which costs can be shared with other haulage jobs and the financial value of the material. Those seeking landbank for their wastes, by-products and products must expect that some of the land within a 20 – 30-mile radius of their facility will not be available to them due to the fact that the farmer prefers to seek alternative sources of bulky organic fertilisers (e.g. animal manures) or prefers not to use them. The percentage of total landbank which might be suitable must be assessed individually through contact with local farmers and/or agronomists. There is no shortcut.

Agricultural landbank for materials which are primarily used for their fertiliser nutrients (including whole and liquid digestates, distillery effluents, poultry manures and sewage sludges) would exist throughout all agricultural land, but would be concentrated in areas where fertilisers are applied more frequently (due to higher crop offtakes). The landbank for off-farm products and wastes would tend to be higher in arable areas and areas with mixed farming and low livestock numbers, since there would be lower tonnages of animal manures and slurries available for spreading. Landbank for bulky, high fertiliser value liquids such as digestates is often low where farmers already have trouble finding sufficient landbank for their slurries for sufficiently long periods during the year. Again, those seeking landbank for their high nutrient wastes, by-products and products must expect that some of the land within a 20 to 30 mile radius of their facility will not be available to them due to the fact that the farmer prefers to seek alternative sources of fertiliser nutrients. The percentage of total landbank which might be suitable must be assessed individually through contact with local farmers and/or agronomists.

Assessment of the potential value of competing bulky organic fertilisers and soil conditioners in any of the four sectors under consideration here (agriculture, forestry, amenity and brownfield land) is complicated because no two materials are the same and because no material contains a mix of nutrients in appropriate concentrations to match crop demand.

Where competition exists between different products, by-products and wastes in forestry and brownfield site restoration, the most cost-effective solution will usually be sought, so products which have the desired characteristics and come with the highest gate fee are likely to be chosen over those with lower gate fees. This may sometimes mean that less desirable products (e.g. with higher P content, higher RAN or higher PTE concentrations) are used. In this case, where wastes are used, compliance with the Waste Management Licensing Regulations (WMLR) (SSI, 2016) should help prevent harm to humans, animals and the environment. Where non-waste materials are used, there are effectively few, or no controls over application rates. In practice, the use of non-waste materials in forestry and land restoration is low, because there is typically a cost rather than a revenue attached to their use. However, there is at least one known case where PAS 110 digestate was used on a restoration site and the rate at which it was applied is not known.

Although wastes are applied in amenity situations, it is not possible to summarise the nature of these applications without studying individual certificates of agricultural benefit/ecological improvement and waste returns submitted to SEPA. In most amenity landscapes, no products or wastes are applied, possibly because it is difficult to source materials with a suitable nutrient mix to establish plantings on amenity sites, the high cost of obtaining exemptions for relatively small individual sites and the difficulties of demonstrating that waste spreading meets the objectives of the exemption, particularly in terms of proving that it delivers either ‘agricultural benefit’ or ‘ecological improvement’. However, “off the shelf” products are also used, including pesticides, fertilisers and soil conditioners such as composts and animal manures. Where competition exists between different products, cost is less important than quality (in terms of the formulation, ease of use, nutrient content and/or other product characteristics). Effective marketing is very important in developing robust markets for new materials in the amenity sector. Several small UK companies have developed very successful brands of bagged soil conditioner and top dressing based on recycled organic materials for the amateur gardening market.

Using publicly available sources and information provided by consultants, SEPA and Scottish Water, the point locations of anaerobic digestion, sewage treatment, composting and distillery and brewery facilities have been mapped (Section 3.4).

1.2.12 Controls in the Sludge (Use in Agriculture) Regulations

Controls on the amount of sewage sludge (or biosolids) which can be applied to agricultural land are detailed in the Sludge (Use in Agriculture) Regulations (1989) (SI. 1989). Sewage sludge is not regulated as a waste when it is used in agriculture and the requirements set out in the Sludge (Use in Agriculture) Regulations (1989) are fulfilled. In the regulations, “agriculture” is defined as “the growing of all types of commercial food crops, including for stock-rearing purposes”. Further guidance is provided in the PEPFAA code (Scottish Executive, 2005), in the Safe Sludge Matrix (ADAS, 2001) and in Defra (2018b) (which is published as being applicable only to England, Wales and Northern Ireland, but the earlier version, which is now somewhat dated, is referred to in the PEPFAA code). Additional safeguards to protect soils, the wider environment and human and animal health are set out in a voluntary industry standard, the Biosolids Assurance Scheme (BAS, 2017), which all sludge producers in Scotland have signed up to.

The Sludge (Use in Agriculture) Regulations (1989) aim to control the build-up of potentially toxic elements (PTE’s) in soil and restrict the planting, grazing and harvesting of certain crops following the application of sludge.

Controls are different, depending on the characteristics of the receiving soil, the crops being grown and the characteristics of the sludge in question. Sludge producers are required to analyse field soils prior to application and at least once every 20 years thereafter. Sludges must be analysed at least once every 6 months. Sludge producers must maintain detailed records of applications of all sludge to farmland. Rules within the Sludge (Use in Agriculture) Regulations which must be complied with are summarised below (SI, 1989).

- Raw and untreated sludges are not permitted on land used for food production. Strictly speaking, untreated sludge is permitted under the current sludge regs. However such sludge would not meet standards in The Safe Sludge Matrix (SSM) and any farmer spreading such sludge would find it difficult or impossible to sell his / her produce. No untreated sludge has therefore been applied to UK farmland for at least the last 20 years. Treated sludges are permitted for application to land growing cereals and oilseed rape. Application is also permitted to growing grass, turf and fruit trees, but harvest intervals apply.
- Treated sludges are permitted for application prior to growing cereals, grass, fodder, sugar beet, oilseed rape and similar crops and fruit trees. Application is also permitted prior to sowing/planting soft fruit, potatoes, vegetables and nursery stock, but controls apply.
- Sewage sludge must not be applied to soils which have pH values lower than 5.0.
- Soil concentration limits are in place for six PTEs - Zn, Cu, Ni, Cd, Pb, Hg - and if concentrations are above these limits sludge cannot be applied. These limits vary for different pH values for Zn, Cu and Ni and in some cases differ between grassland soils and those used for arable cropping. Recommended limits are also in place for Cr, Mo, Se, As and F (Scottish Executive, 2005).

- Maximum permissible average annual rates of PTE addition over a 10-year period must not be exceeded for the above eleven PTEs.

In the past, sludge applications were mainly based on crop N requirement, which has sometimes resulted in over-application of P and under-application of K, since biosolids typically contain much greater concentrations of P than K. Nowadays, P is usually taken into account, but there is evidence that some farmers using sewage sludge are still under-applying K (A. Cundill, pers. comm.).

The Sludge (Use in Agriculture) Regulations (1989) do not apply to land used for forestry or amenity, to brownfield sites or to agricultural land used to grow non-food crops.

The is currently no direct method of mapping the controls in the Sludge (Use in Agriculture) Regulations but proxy indicators such as the location and capacity of sewage processing facilities have been included in the GIS data set (Section 3.4).

1.2.13 Controls under Waste Management Licensing Exemption rules

In Scotland, recycling waste organic materials to agricultural and non-agricultural land is regulated by The Waste Management Licensing (Scotland) Regulations 2011, as amended (SSI, 2011; SSI, 2016). Applications of materials classified as waste may be undertaken on agricultural and non-agricultural land under exemptions from waste management licensing via Paragraph 7 (agriculture, forests, parks etc.). They may also be undertaken on non-agricultural land under a Paragraph 8 (storage and spreading of sludge on non-agricultural land) or Paragraph 9(1) (remediation or restoration) exemption. The person or organisation wishing to spread the waste must demonstrate that the application will result in either agricultural or ecological improvement otherwise it is regarded as disposal. The spreading activity must also comply with the Relevant Objectives of the legislation. To that end, the waste must be managed without endangering human health and without using processes or methods which could harm the environment and in particular without:

- risk to water, air, soil, plants or animals;
- causing nuisance through noise or odour, or
- adversely affecting the countryside or places of special interest.

In practice, this means that the nature of any agricultural benefit or ecological benefit must be defined and the application rate of the waste in question justified. Application rates of wastes to agricultural crops (under Paragraph 7 exemptions) are traditionally relatively low to match the demand of a single crop or crops within a rotation.

Application rates of wastes to land being restored for the purposes of non-food crop production, forestry or amenity have traditionally been much higher. For example, rates of up to 500 dry tonne/ha were typical (SNIFFER, 2010). SEPA has recently begun reducing the maximum permitted application rates of wastes in land restoration, simply because there is considerable evidence of poor quality restoration having taken place in the past. In some cases, nutrients were applied greatly in excess of need and the potential for pollution was high. In current practice, SEPA have adopted limits of no more than 2,000 kg/ha of phosphate and no more than 750 kg/ha of readily available N where bulky organic materials are being used in brownfield restoration. These limits have not yet been set in statute or published in the form of guidance other than as part of the new landfill restoration form.

There may be cases in future where higher application rates could be justified following analysis of the soil for appropriate parameters. For example, the presence of certain types of clay in soils of very low phosphate status can result in applied phosphate being very strongly adsorbed, thus preventing crop uptake.

Whether a material is classified as waste when used in a particular way can be confusing. Table 1.23 summarises the status (waste or not) of the main materials considered in this project.

Table 1.23. Status (waste or non-waste) of materials considered in this project when being applied to land.

Material	Qualification	Status	Main relevant legislation
Animal manures and slurries	• Derived from and used on the same farm and applied to land	non-waste	CAR GBR 18[1]
	• Derived on one farm and used on another farm	non-waste	CAR GBR 18[1]
	• Derived at non-farm locations (e.g. abattoirs, zoos, pet shops)	waste	WML Regs[2]
Anaerobic digestates	• PAS 110-accredited and compliant with SEPA position statement (SEPA, 2017b) when applied to land.	non waste	CAR GBR 18[1]
	• Derived from crop and/or distillery by-products and compliant with SEPA position statement when applied to land.	non waste	CAR GBR 18[1]
	• Any non-PAS 110 digestate other than the above.	waste	WML Regs[2]
Distillery and other drinks wastes	When applied to land	waste	WML Regs[2]
Composts	• PAS 100-accredited and compliant with SEPA position statement (SEPA, 2017a) when applied to land.	non waste	CAR GBR 18[1]
	• Any non-PAS 100 or off-specification (off-spec.) compost.	waste	WML Regs[2]
Sewage sludge	• Applied to agricultural land	waste	SUiA Regs[3]
	• Applied to any other type of land	waste	WML Regs[2]
Pulp, paper and card wastes	When applied to land	waste	WML Regs[2]
Non-meat food wastes	"	waste	WML Regs[2]
Meat, fish and animal origin food wastes	"	waste	WML Regs[2]
Water treatment sludges	"	waste	WML Regs[2]
Plant tissue wastes	"	waste	WML Regs[2]
Waste ash	"	waste	WML Regs[2]
Wood processing wastes	"	waste	WML Regs[2]
Wastes from chemical production	"	waste	WML Regs[2]
[1]Controlled Activities Regulations General Binding Rule 18; [2]Waste Management Licensing Regulations; [3]Sludge (Use in Agriculture) Regulations.			

Only the application of wastes (and sewage sludges in land restoration and forestry) are subject to the Waste Management Licensing Regulations (SSI, 2011). The application of sewage sludges in agriculture is regulated through the Sludge (Use in Agriculture)

Regulations 1989 (SI, 1989). Animal manures and slurries are not regulated as wastes unless they are removed from the farm of origin and used in non-agricultural applications.

For compost and digestate, materials that comply with either BSI PAS 100 (BSI, 2018) or PAS 110 (BSI, 2014) and additional requirements set by SEPA are no longer classified as waste and are therefore outside the scope of the WMLR, provided they are spread in accordance with SEPA's position statements (SEPA, 2017a; SEPA, 2017b). Similarly, non-waste-derived digestates coming from the whisky sector and crop-fed AD plants are not regulated as waste under the WMLR. Additionally, materials defined as products that are spread to land (e.g. bagged chemical fertilisers, crushed scallop shells, agricultural lime, pesticides etc.) are also outside scope of WMLR. However, controls under water pollution legislation still apply to all these materials.

There is currently no direct method of mapping the constraints of controls under Waste Management Licensing Exemption rules but the location of facilities such as distilleries and breweries that systematically give rise to materials that are land spread under exemptions have been included (Section 3.4).

1.2.14 Risk of pathogen transfer to food crops and water bodies

Some organic material types being applied to land carry a risk of pathogen transfer to food crops and water bodies. The main ones include animal manures, abattoir wastes, sewage sludge (particularly untreated sludges), composts and digestates.

Although untreated sludge spreading is still permitted on non-food crops under very specific conditions, application of untreated sludges in UK agriculture is contrary to best practice guidance (e.g. the Safe Sludge Matrix). None of the UK water companies allow untreated sewage sludges to be spread on agricultural land now. The main pathogens of concern in these materials include: *E. coli* (in particular *E.coli* O157), *Salmonella* species, *Cryptosporidium* species, *Campylobacter* species, *Giardia* species and cytopathic rotaviruses and enteroviruses. The significance of the risks is dependent on:

- pathogen types and numbers in the material concerned
- pathogen death rates following application to land
- the land to which the material is applied (e.g. avoiding slopes and buffer zones around water bodies/watercourses) and
- the manner in which the materials are applied (e.g. application rates, application methods [e.g. injection, cultivations following application], application timing in relation to weather and the time of year).

The risks from pathogen transfer to food crops and water bodies are effectively managed in the UK through both legislation (The Sludge (Use in Agriculture) Regulations (SI, 1989)) and the Controlled Activities Regulations (specifically GBR 18, SEPA, 2019a), through the Safe Sludge Matrix and comprehensive and rigorous farm assurance scheme rules. Risks from pathogens present in sewage sludge are managed in agriculture through compliance with the Sludge (Use in Agriculture) Regulations (1989) (SI, 1989, Section 1.2.12). There are further rules and some prohibitions relating to sewage sludge for crops assured under the various assurance schemes operating in Scotland (Section 1.2.14).

Pathogen risks to crops, animals and humans from application of wastes containing animal by-products (e.g. abattoir wastes, food-derived composts and digestates) are managed to some extent through the Animal By-Products Regulations (SSI, 2013). For example, there are grazing prohibitions of 3 weeks for cattle and sheep and 8 weeks for pigs following application of composts and digestates containing animal by-products.

Pathogen risks to crops, animals and humans from applying abattoir wastes, composts and digestates are also managed by the crop assurance schemes operating in Scotland by various means. The assurance scheme rules are least strict for non-edible crops and most strict where crops can potentially be eaten raw. For example, Quality Meat Scotland (QMS) and Scottish Quality Crops (SQC) prohibit non-certified composts and digestates, and untreated abattoir wastes, and there are various rules on using certified composts and digestates (QMS, 2017a; SQC, 2018). SQC launched its own green digestate scheme in 2019 which aims to allow the use of crop-based digestate from certified plants to be used on arable land used to grow malting barley. These measures will also help prevent pathogens from entering water bodies.

Pathogen risks to fresh produce are particularly high: they are minimised through compliance with additional rules set out in certification schemes e.g. animal manures must be stacked for at least 6 months or composted for at least 3 months prior to use but they, along with composts and digestates, are not permitted on ready to eat crops (Red Tractor Assurance, 2019). Intervals between applying sewage sludge and growing fresh produce are much longer than those required by law under the Red Tractor Fresh Produce Assurance Scheme (Red Tractor Assurance, 2019).

Organic material types which carry a high risk of pathogen transfer to food crops and water bodies tend not to be used in amenity situations, although if they were then the Controlled Activities Regulations would apply, which would help limit pathogen transfer to water (SEPA, 2019a).

Organic material types which carry a high risk of pathogen transfer to food crops and water bodies (e.g. untreated sewage sludge in particular, and off-specification composts and digestates) are frequently used in land restoration. The main control in terms of avoiding pathogen contamination of water bodies is the Controlled Activities Regulations (GBR 18; SEPA, 2019a). However, certain conditions stipulated by SEPA during land restoration may also help limit the transfer of pathogens to water bodies, for example the requirement to cultivate in untreated sludges and the requirement to limit tonnages applied in order to keep the amount of applied phosphate below 2,000 kg/ha (author’s experience in managing land restoration sites). If the compost intended for use in restoration was off-specification, then the reason for failure to achieve certification must be declared and SEPA staff may choose to ask for additional controls over the use of the material in question.

One systematic mitigation measure that is designed to protect water quality and human health from pathogen transfer to water bodies is the no-spread buffer strips stipulated under GBR 18 and these have been included in the GIS data set (Section 3.1).

1.2.15 Controls on designated sites

Designated sites include Sites of Special Scientific Interest (SSSIs), Special Protection Areas (SPAs), Special Areas of Conservation (SACs), Ramsar wetland sites, National and Local Nature Reserves, sites listed in the “Inventory of gardens and Designed Landscapes”, National Scenic Areas, National Parks and Regional Parks.

At 31 March 2016, there were 1,423 SSSIs in Scotland, covering a total of 1,022,000 hectares (13% of Scotland’s land area). SNH has the power to regulate SSSI sites in terms of the Wildlife and Countryside Act 1981 (as amended) and the Nature Conservation (Scotland) Act 2004. Owners of land classed as an SSSI, should hold a Schedule of Operations Requiring the Consent of SNH (“ORCs”) in relation to that land. In most cases they will be prohibited from applying organic materials to the land due to the risk of them changing fundamentally important aspects of the habitat or ecosystem on the site.

Special Protection Areas (SPAs) are designated under the 2009 EC Wild Birds Directive (consolidated version of 79/409/EEC) to safeguard the habitat of a number of wild bird species. The area of SPAs is around 1,297,000 ha. Special Areas of Conservation (SACs) are designated under the 1992 EC Habitats Directive to protect certain species and habitat types throughout the EU. The area of terrestrial and inshore marine SACs was 2,367,000 ha in 2017. Ramsar sites are designated under the Convention on Wetlands of International Importance. At 31 March 2017, there were 253 SACs, 153 SPAs and 51 Ramsar sites in Scotland. Although a few of these sites might be on farmland and thus receive occasional applications of farmyard manures, it is unlikely that they will be suitable for application of other organic material types. Similarly, national and local nature reserves in Scotland (which in total cover around 122,700 ha, or 1.5% of Scotland's land area) are often managed in traditional ways which involve part-time grazing with farm animals, but it is unlikely that they will be suitable as land for application of manures produced elsewhere or other organic material types.

There are over 300 sites listed in the "Inventory of gardens and Designed Landscapes", which range in size from around 1 to over 1,000 ha (Historic Environment Scotland, 2016). None are likely to be suitable as landbank for regular applications of organic materials. National Parks, Regional Parks and National Scenic Areas are made up of a mix of land uses including farming, forestry, amenity areas and towns and villages. They cover around 1.63 million ha (20.4% of Scotland's land area). Sites may be protected by more than one designation. For example, around 52% of SPAs and 86% of Ramsar sites are also designated as SSSIs. There are no controls on applications of organic material in agricultural, forestry or amenity land in designated sites areas other than where those listed elsewhere in this document which are relevant.

All the designated sites listed above have been mapped and are included in the GIS dataset (Section 3.8).

1.2.16 Farm Assurance Scheme rules and produce buyers rules

Almost all Scottish fresh produce is now sold as "farm assured", with most markets requiring produce to be assured under one (or sometimes more than one) of several assurance scheme(s). Assured crops are produced according to documented quality management systems in accordance with scheme standards, which aim to produce safe food whilst minimising impact on humans, animals and the environment. There are increasing requirements within the schemes to enhance soil quality and address the sustainability of production systems.

The rules for the main farm assurance schemes in Scotland, which are those managed by Quality Meat Scotland (www.qmscotland.co.uk/), Scottish Quality Crops (www.sqcrops.co.uk/) and the UK wide Assured Food Standards (Red Tractor) (https://assurance.redtractor.org.uk/) are available on public websites. The LEAF (Linking Environment and Farming) Scheme (https://leafuk.org/) also publishes its standards online (LEAF, 2019). In these cases, it is relatively easy to determine whether named material types and categories are permitted (or not) for use under specified conditions. All of the above assurance schemes require that farmers use approved fertilisers and soil conditioners in a responsible, sustainable manner and set out rules for doing so. Where a farmer has a question, for example, where a new material comes onto the market, it is his responsibility as a member of one or more certification schemes, to contact the scheme administrator to ask for permission to use the material in the manner intended.

In addition, most retailers require their food suppliers to comply with one or more major assurance schemes, but some also own their own schemes with which their suppliers must also comply, for example Tesco Nurture (www.globalgap.org/uk_en/for-producers/globalg.a.p.-add-on/nurture-module/); Tesco Stores Ltd., 2019). This scheme, the standards for which are publicly available, is available as an "add-on module" to certification with "Global Gap", a worldwide set of standards for good agricultural practice. Others, such as Marks and Spencer's "Field to Fork", are effectively private with the scheme rules being available to members only. It is not possible to obtain detailed information about which off-farm materials are permitted and under which conditions in this standard.

The main farm assurance schemes operating in Scotland and brief summaries of their rules on using organic materials as fertilisers and soil conditions include:

- *QMS Cattle and Sheep Scheme* (QMS, 2017a). Includes broad statements on the need to apply fertilisers including organic fertilisers in accordance with relevant regulations and good agricultural practice; includes references to appropriate guidance and advises members to seek professional advice. Provides guidance on fertilisers approved under the scheme, some of which can be used only under specified conditions. Approved fertilisers include manures, slurries, silage effluent, treated sewage sludge, farm-based non-certified digestates, distillery and brewery digestates and crustacean shells. PAS100 certified composts and PAS 110-certified digestates are also permitted, but only where additional requirements on physical contaminants (over and above those set out in the standards) are met. The QMS limit for plastic is 50% of that stated for PAS 100 composts and 8% of that for PAS110 digestates. Scheme requires members to retain evidence to demonstrate compliance with use of farm-derived and off-farm fertilisers and soil improvers.

- *QMS Pigs Assurance Scheme* (QMS, 2017b). Gives less detail than the above scheme, but refers to it, which effectively means that the standards relating to use of imported organic fertilisers and soil conditioners are the same as for the QMS Cattle and Sheep Scheme.

- *SQC (Scottish Quality Crops) Farm Assurance Scheme* (SQC, 2018). The standards include broad statements on the need to apply fertilisers including organic fertilisers in accordance with relevant regulations and good agricultural practice; includes references to appropriate guidance and advises members to seek professional advice. Provides guidance on fertilisers approved under the scheme, some of which can be used only under specified conditions. Approved fertilisers include manures, slurries, silage effluent, treated sewage sludge, "green digestates" which should be certified under SQC's own scheme, distillery and brewery digestates and crustacean shells. PAS100 certified composts and PAS 110-certified digestates are also permitted, but only where additional requirements on physical contaminants (over and above those set out in the standards) are met. The SQC limits for plastic are the same as those used by QMS.

- *UK Red Tractor Assurance Schemes* including those for Crops, Fresh Produce, Dairy, Beef and Lamb, Pigs and Poultry (e.g. Red Tractor Assurance, 2018; 2019). Includes several broad statements. For example, the Fresh Produce Scheme states that all fertilisers/soil improvement products used must be legal, suitable for their intended use and applied in a manner that prevents contamination, pollution and minimises the risk of microbial contamination. Permitted products include, but are not limited to manures, (not necessarily certified) composts, digestates, treated sewage sludges, biostimulants and plant strengtheners. All such materials must have agricultural benefit and must be applied in accordance with relevant regulations, good agricultural practice and in accordance with the Red Tractor "Safe Applications to Land Matrix" (Red Tractor Assurance, 2019).

- *LEAF Marque* (Linking Environment and Farming) (LEAF, 2019). Does not specify permitted or prohibited fertiliser types. Requires that farmers keep field records to prove that fertilisers have been applied at appropriate rates and timings and have been placed accurately.

In addition to the farm assurance scheme rules, some produce and commodity buyers have additional rules and prohibitions on the application of off-farm wastes and products, many of which are not easily referenced. For example, malting barley buyers are reportedly unwilling to buy grain from land which has been amended in the past with some types of organic materials (e.g. sewage sludge or compost). However, this rule does not appear to be published anywhere.

Similarly, in a recent WRAP-funded project (ZWS, 2018), several growers and grower group representatives said that their buyers/markets did not allow composts (or other off-farm organic materials) to be used on their crops. They were not able or willing to provide any evidence of these prohibitions in written form. It may be the case that buyer's representatives simply discourage the use of composts (or other forms of risk-taking as they see it) during the regular discussions of crop performance which take place at the production sites and pack-houses. There does seem to be a culture of nervousness, in some cases bordering on fear (on the producer's side) in the relationship between the large growers/grower groups and their main buyers. That makes sense, because in some cases, up to 70% of a holding's crop may go to a single supermarket buyer. The growers are keen to maintain a positive working relationship with their powerful key buyers and do not want to jeopardise their contract (and their company and the jobs of staff within it) by taking any form of risk. Several growers stated that they did not want to take the unnecessary risk of using compost when it may or not bring benefits in the short or long term.

In summary, some farmers that might be interested in taking off-farm wastes and products will not be able to do so because their buyers discourage or prohibit it. This means that simple estimates of landbank for off-farm wastes and products based on parameters such as land area, land capability for agriculture and crop type would have to be reduced, particularly where large areas of malting barley or high value horticultural crops were being grown.

There is currently no direct or indirect method of mapping the impact of Farm Assurance Schemes and they are not considered as part of the GIS dataset.

1.2.17 Organic farming regulations and rules

Around 2.2% of agricultural land in Scotland is certified organic (Scottish Government, 2017). The UK organic certification schemes (of which five operate in Scotland) contain clearly defined rules on using organic materials as fertilisers and soil conditioners. The certification bodies operating in Scotland are:

- The Scottish Organic Producers Association (SOPA, www.sopa.org.uk/)

- The Soil Association (www.soilassociation.org/certification/?gclid=EAIaIQobChMIopiR__zC4gIVz7ztCh1bNwNNEAAYASAAEgLJTvD_BwE)
- The Organic Food Federation (www.orgfoodfed.com/)
- The Organic Farmers and Growers (https://ofgorganic.org/)
- The Biodynamic Agricultural Association (http://bdcertification.org.uk/index.php/bd-certification/)

All, apart from SOPA, publish their organic standards on their websites.

The rules with which organic farmers and growers must comply are based on the European Organic Farming Regulations (Defra, 2019b; European Union, 2018; Welsh Assembly Government, DARDNI, Scottish Government and Defra, 2010). However, the rules published by each certification body (termed "Organic Standards") differ to some extent from them and some, in particular those of the Soil Association, are stricter than the minimum EU regulations. As a general rule, no synthetic fertilisers are permitted in organic farming, and there are defined lists of (mainly organic) fertilisers in the various certification schemes. Materials are only permitted for use if there is a need for them (which must be proven through soil or tissue analysis) and only at rates which provide the minimum amount of nutrients for crop production. Fertilisers which are permitted under these conditions include a wide range of materials including composts and digestates, blood meal, bone meal, seaweed extracts and meal, sawdust, wood chips, dairy products, fur and wool. Manures from intensive animal production units are not permitted.

Note that for organic produce sold through the multiple retailers, organic certification (through one of the seven UK organic certification bodies) is not sufficient, and assurance through at least one additional scheme, such as those listed in Section 1.2.16 is usually required.

There is currently no direct or indirect method of mapping the impact of organic farming regulations and they are not considered as part of the GIS dataset.

1.2.18 Requirement for nutrients and organic matter in land restoration

Where there is no sufficient topsoil available, there is a need for defined amounts of nutrients and organic matter if restoration is to be successful and these could be applied in the form of either products or waste materials. Due to the high cost of non-waste fertilisers and soil conditioners, materials applied to restore and improve soils in land restoration are almost exclusively wastes and sewage sludges. Controls on their application are therefore covered under Sections 1.2.12 and 1.2.13.

It would in theory be possible to over-apply bulky organic materials such as PAS 100 composts and animal manures on restoration sites, thus creating environmental problems. However, the author of this section is aware of it happening only rarely. The main reason that it is unlikely to happen widely is that certified composts are typically sold at several pounds per tonne (including a sometimes substantial haulage cost). In the case of animal manures, most farmers want to apply their own materials to their own land and if wishing to export it, they almost always do so at a price. Restoration managers have limited or no funds to pay for bulky organic materials and instead require a gate fee to pay for the high cost of restoring derelict land. So the relatively high cost of bulky non-waste materials means that land restoration companies would tend to use the minimum amount possible if they are forced to use it, rather than be paid to take alternatives.

1.2.19 The cost of materials (financial acceptability in different sectors)

The prices which operators in different sectors (agriculture, amenity, forestry and land restoration) are willing to pay for fertilisers and soil conditioners differ.

Amenity users (such as golf course managers, landscapers and amateur gardeners) are often prepared to pay high prices for high quality products which they believe to be tailored to their needs. For example a 25:0:0 liquid fertiliser being sold into the turf management sector by Amenity Land Solutions at £51 for 10 litres (www.amenity.co.uk/spring-summer-liquids/icl-greenmaster-liquid-high-n-25-0-0-2mg0-te.html) means that the N within it costs £12.75 per kg. Fertilisers and soil conditioners being sold into the amenity market are usually considerably more expensive than those being sold into agriculture.

Most farmers buying bulk fertilisers would purchase the cheapest available product. For example, UK-produced ammonium nitrate is currently being sold into agriculture at around £263/tonne (AHDB, 2019). It contains 34.5% N, therefore the N within it costs £0.75/kg. Imported ammonium nitrate is slightly cheaper than this. The economics of farming are such that most farmers are keen to use the cheapest fertilising and soil conditioning products available to them. They are usually also keen to use products which are free or for which they are paid a fee to use. The author's regular contact with farmers and organic waste processers has shown that farmers' understanding of what their assurance schemes and buyers permit in terms of use of off-farm materials is unfortunately sometimes poor. As a result, there have been several cases in recent years where Scottish farmers have applied materials of types prohibited by their assurance schemes, or have applied approved materials in ways prohibited by their assurance schemes, and they have been served with non-compliance notices.

The pressure for low prices in fertilisers and soil conditioners is more extreme in forestry and brownfield site restoration than in agriculture (SEPA, 2018a). Margins are extremely tight and operators have little or no money to spend. Foresters often choose to apply no fertiliser at all during planting and production, and both foresters and land restoration companies almost always require a gate fee to take waste for beneficial use as fertilisers or soil conditioners.

The cost of materials is included indirectly in the GIS data set by the mapping of point sources that systematically generate organic materials that can be spread to land (Section 3.4). In addition, the mapping of land that cannot legally be spread to (Section 3.1), can be used to evaluate the impact on a bespoke basis.

1.2.20 Carbon footprinting

At present, there is no requirement to assess the carbon footprint of waste treatment facilities, or the way in which organic materials are used in most sectors. In fact the carbon footprints of some AD plants, which receive government subsidy for renewable energy generation are likely to come out rather badly in any truly honest carbon footprinting exercise, given the significant distance which some of the feedstocks are transported prior to treatment and the significant distance which the digestate is transported after treatment.

There can also be greenhouse gas emissions associated with storage of digestate, with application of digestates and with manufacture of synthetic fertiliser N used to replace the significant proportion of applied N lost through ammonia volatilisation and nitrate leaching, even from digestate applied using best practice.

There is increasing requirement for carbon footprinting in the farming sector, through the farm assurance schemes, although some of the programmes being used at present take little account of the carbon emissions associated with materials before they arrive at the farm.

There is no GIS dataset associated with this topic.

Given the urgency of the need to mitigate the effects of climate change globally, it is possible that increasingly accurate and honest carbon accounting will be required in future, which take full account of emissions associated with all aspects of waste treatment, transport and use of wastes and products on land. If this does happen, and/or a price is to be set for carbon, then waste treatment processes and the way in which the materials being considered under this project are used on land may change in a significant way. Possible changes might include:

- The existence of a greater number of smaller waste treatment plants (particularly AD plants) which are situated closer to their waste suppliers and closer to their landbank.
- A move towards increased separation of whole digestates to produce fibre, inorganic or biorefinery products and ultra-low nutrient liquids which are discharged to sewer, river or waste water treatment.
- Increased drying/incineration of some types of organic wastes to reduce their water content and therefore the cost and carbon emissions associated with haulage, storage, spreading and the deleterious impacts (to soils) of spreading heavy materials to land.
- A change to renewable energy to power waste treatment plants.
- A ban on organic wastes to landfill (proposed in Scotland, but postponed at present), coupled with sustained efforts to improve organic waste treatment processes in order to improve the quality of composts and digestates.
- Direct subsidies or incentives to reduce or eliminate production of organic products (and therefore by-products) with a high carbon footprint.

2 Amount and characteristics of agricultural and non-agricultural materials that could be available for land application

2.1 Introduction

This section outlines the tonnages of different types of organic and inorganic materials produced in Scotland. The limitations in respect of the data presented are stated in each case. This section also describes the agricultural benefits associated with application of each material to land and summarises the geographical location of both outlets and landbank.

It has been a complex job to produce acceptably accurate estimates of the tonnages of bulky organic and inorganic materials (including those defined as animal manures, sewage sludges, products and wastes) which have been applied to land in recent years. We have covered a list of the materials which were agreed with SEPA. The list has been simplified in order to group different types of waste materials into thirteen broad categories. We have allocated one or more waste codes to each category, where appropriate.

This project concerns mainly materials which contain plant nutrients and organic matter. It also covers inorganic nutrient-containing materials including waste ash and gypsum, but it does not include inert or relatively inert heavy wastes such as soil, stones, tar planings and recycled aggregate fines as agreed with SEPA. Of the wastes permissible under Exemptions to the Waste Management Licensing Regulations (Paragraphs 7 and 9), no records have been found of textile, fur and leather wastes (04 01 and 04 02) or slow sand filter sand (and similar) from urban waste water or clean water treatment plants (19 08 99 and 19 09 99), having been applied to land in Scotland. For that reason, these materials are not included in this study. Table 2.1 shows the main categories of materials covered in this study and the total tonnages of fresh material of each applied to land in 2017 (2018/19 for sewage sludge and clean water sludge and 2019 for animal manures and slurries).

Table 2.1. The categories of organic and inorganic materials covered in this study, the (fresh/wet) tonnages applied to land annually (most recent data) and the relative percentages of each (out of the total tonnage of all materials applied).

Category of material	Tonnage (fresh weight) of each material	% of total tonnage applied
Animal manures and slurries* (2019)	11,429,935	86.6
Anaerobic digestates (waste and non-waste) not including sewage sludge, 2017	751,891	5.7
Drinks processing wastes (not incl. digestates, 2017)	459,546	3.5
Compost (waste and non-waste, 2017)	224,925	1.7
Sewage sludge (2018/19)	221,214	1.7
Pulp, paper and card wastes (2017)	24,109	0.2
Non-meat food wastes (2017)	23,264	0.2
Food processing wastes (meat, fish, 2017)	18,254	0.14
Clean water treatment sludge (2017)	15,466	0.12
Plant tissue wastes (2017)	12,140	0.09
Waste ash (2017)	10,237	0.08
Wastes from wood processing (2017)	1,906	0.014
Wastes from chemical production including gypsum (2017)	1,162	0.006
Total	**13,194,049**	100.00
*This does not include manures excreted directly onto fields from grazing animals.		

The decision to use the most recent data for animal manures and sewage sludge (rather than have all data from the same year) was taken since the tonnages of each changed since the previous year. We felt that it was important to use the most recent data possible, since these materials make up such a large proportion of the total annual tonnage of bulky materials applied to land. Figure 2.1 shows the most important seven categories of materials (in terms of the percentage of total annual tonnage applied to land, based on the figures in Table 2.1). Tonnages of the remaining eight categories of materials have been added together.

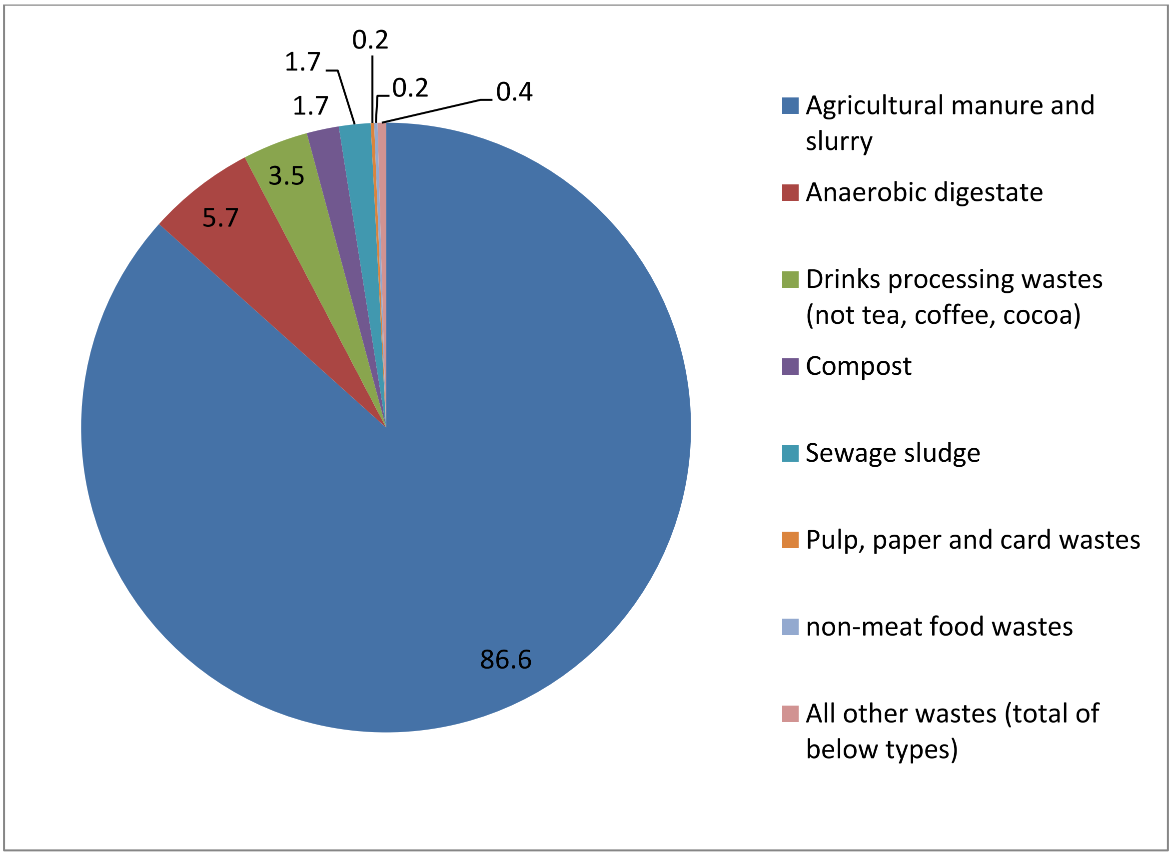

Figure 2.1. The percentages that each of the six most important materials applied (and all other waste types added together) make up, out of the total annual tonnage applied.

Table 2.1 and Figure 2.1 clearly show that in terms of tonnages applied to land, livestock manures are by far the most important, representing almost 87% of the total wet tonnage of all materials applied. Significant tonnages of anaerobic digestates, non-digestate drinks processing wastes (effectively distillery and brewery wastes), composts and sewage sludge are also produced (between around 221,000 and 752,000 t of each per annum). Over 20,000 t each of pulp, paper and card wastes and non-meat food wastes are applied annually to land. Tonnages of all other materials are much less significant and together represent only 0.4% (59,165 t) of all materials applied.

We have produced simple summaries of the tonnage of each category of material applied and/or produced annually, the appropriate waste codes (where relevant), the key agricultural benefits from each material and the main location(s) of both outlets and landbank for each material, where known (Section 2.2 to 2.14).

There was insufficient time and resources available to allow the project team to contact individual waste producers (apart from in a very few cases, where detailed). For that reason, estimates have been based on published surveys and reports, contact with various staff members in SEPA and Scottish Water and government-funded reports. Key references and information sources for each material type are provided in sections on individual material types (Sections 2.2 to 2.14).

Where reliable information on tonnages produced (rather than applied to land) is available for a particular material type, then these are quoted in Tables 2.2 to 2.14. In some cases, the tonnage figures for materials are fairly robust, but for others this is not the case. The data is further discussed and interpreted in Sections 2.2 to 2.14. The means by which tonnages applied to land were then calculated have been defined and the robustness of the data has been discussed. For all the wastes in Sections 2.4 and 2.7 to 2.14, the only source of tonnages applied to land were unpublished data held by SEPA. The project team are aware that this data will be subject to errors and the true figures for tonnages applied to land may be much lower than our estimate (where estimates rely largely on the tonnages gained from waste management licencing exemption applications (paragraphs 7, 9 or 50), or much higher (where more material was applied than claimed in the waste returns). These errors are likely to be particularly important for drinks processing wastes (not including digestates), where the tonnages involved are significant.

Tables 2.2 to 2.14 are simple representations of extremely complex datasets. It is important to simplify the data in order to begin to assess and interpret it. Each of the materials listed in these tables is discussed in more detail in Sections 2.2 to 2.14 in relation to the reasons for grouping materials as we have done, the sources of data used, justifications for the information provided and justifications for the forecasts made for future likely production tonnages (on which the work in Objectives 4 and 5 are based).

Table 2.2. Animal manures and slurries not classed as waste other than non-agricultural animal manures e.g. from shows, marts, petting zoos (see Section 2.2).

			Total tonnage produced (all types in 2019) 11,429,935 t[1] (↓ by 2.8% on 2017) (↑ by 3.8% on 2015)		
Manure type	**No. of wet tonnes produced in Scotland (2019)**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets[3]**	**Summary of geographical location of landbank[4]**
Animal manures and slurries (all types)	Solid manure – 5,694,546 t, Liquid slurry - 5,735,389 t, Total manure - 11,429,935 t			National share (all types of manure): Aberdeenshire 18%, Dumfries & Galloway 17%, Scottish Borders 9%, Highland 7%, S Lanarkshire 7%	
Cattle manure (solid) $1m^3 = 0.7$ t	Dairy - 373,907 t Beef – 4,575,136 t Total – 4,949,043 t	Major and secondary nutrients (N, P, K, Mg, S) and organic matter.	*Solid manures:* Few risks other than high Cu and Zn in intensively fed livestock, particularly in pig and poultry manures. Anthelmintics and other veterinary medicines can be present in some manures, particularly fresh ones. Worm eggs and intestinal pathogens (such as *E. coli*) can be present, particularly in fresh manures.	National share (solid cattle manure): Aberdeenshire 27%, Scottish Borders 12%, Highland 8%, Moray 7%	Animal manures are typically spread on the farm on which they are produced. Where they are transported, for example in “straw for muck deals”, the haulage distance is rarely more than about 30 km.
Pig manure (solid) $1m^3 = 0.7$ t	272,009 t	"		National share (solid pig manure): Aberdeenshire 72%, Scottish Borders 24%	
Sheep manure (solid) $1m^3 = 0.7$ t	366,868 t	"		National share (all types of sheep manure): Scottish Borders 36%, Highland 14%, S. Lanarkshire 7%	
Poultry manure (layer and broiler/turkey) $1m^3 = 0.7$ t	106,626 t	"		National share: (layers): Scottish Borders 39%, Fife 16%, Aberdeenshire 11%, Dumfries & Galloway 10% National share (broilers): W Lothian 25%, Perth & Kinross 17%, Fife 17%, Edinburgh 11%	
Cattle slurry (liquid) $1m^3 = 1$ t	Dairy – 2,853,356 t Beef – 2,458,961 t Total – 5,312,317 t	Major and secondary nutrients (readily available N (RAN), P, K, Mg, S).	*Liquid manures (slurries):* Risks as for solid manures, but also risk of ammonia volatilisation and nitrate leaching from high RAN liquids.	National share (cattle slurry): Dumfries & Galloway 32%, S. Lanarkshire 9%, Orkney 8%, E. Ayrshire 7%	
Pig slurry (liquid) $1m^3 = 1$ t	363,655 t	"		National share (pig slurry): Aberdeenshire 51%, Scottish Borders 14%, E. Lothian 13%	
Sheep slurry (liquid) $1m^3 = 1$ t	59,417 t	"		National share (all types of sheep manure): Scottish Borders 36%, Highland 14%, S. Lanarkshire 7%	
Animal manure (other), e.g. goats, horses, llamas, ostriches, buffalo	Likely to be insignificant	Variable, depending on species and feeding regime. Usually major and secondary nutrients and organic matter.		No data available	
Non-agricultural animal manures, e.g. from shows &, marts. EWC code 02 01 99. (to land by Para 7 only).	1,540 t 2017 (↑ by 62% on 2016)	"		1,290t derived from Dumfries & Galloway, the potential remaining was not recorded.	
[1]Figures on tonnage to land based on the method described in Section 3.2 of this report; [2]Information on agricultural benefit from SRUC TN650 (SRUC, 2013); [3]Data on location of outputs from Scottish Government (2019); [4]information on landbank is based on the project team’s understanding of the Scottish livestock sector.					

Table 2.3. Anaerobic digestates

(See Section 2.3).

		Total tonnage produced (all types excluding waste water treatment [i.e. sewage sludge] in 2017) 8,159,575 t[1] (~ 40 times higher than in 2014 - not possible to determine % increase) **Total tonnage applied to land produced (all types excluding sewage sludge in 2017) 751,891 t[2] (~5.3 times higher than in 2014).**				
Digestate from merchant AD	**Relevant waste codes**	**No. of wet tonnes produced in Scotland (2017)**	**Key agricultural benefits[3]**	**Potential risks[4]**	**Summary of geographical location of outlets (all digestate types)[5]**	**Summary of geographical location of landbank (all digestate types)[6]**
Total digestate produced		250,676 t	*Separated liquor and whole digestates (all types):* major and secondary nutrients (particularly RAN, with some P, K, Mg, S).	*Separated liquor and whole digestates (all types):* Ammonia volatilisation and nitrate leaching from high RAN liquids. Potential presence of human, animal and plant pathogens and weed seeds dependent on whether material is pasteurised. High salt and sodium concentrations in some types of liquid digestate. High chemical and biological oxygen demand.	There were 43 anaerobic digestion plants in Scotland in 2017 other than those in waste water treatment (sewage sludge) facilities. There are now around 53 (link to section and map in Objective 2). Most plants (other than that in the Western Isles) are situated in the eastern arable areas of Scotland, but there are around 15 farm-based plants situated in SW Scotland. There are very large areas of Scotland to the north and west of the central belt which have no AD Plants.	Where digestate is spread to land, it's usually spread within a 20 mile radius of the production site and in the case of farm-based digestates, often on the farm where purpose-grown crops have been produced. However, there are cases where digestate is transported routinely from west coast merchant AD plants to the east coast arable areas in order to find agricultural markets. This can involve transport distances of over 160 km. See section 3.4.3 for details on locations of AD plants)
PAS 110 digestate only		67% of total – 167,953 t				
Waste only		33% of total – 82,723 t				
Digestate, whole (PAS110/waste)	19 06 03, 19 06 04, 19 06 05, 19 06 06	236,310 t				
Digestate, fibre (PAS 110/waste)	19 06 04, 19 06 06	5,799 t				
Digestate, liquor (PAS 110/waste)	19 06 03, 19 06 05	8,568 t				
Digestate from farm-based AD						
Total digestate produced		417,935				
Digestate, whole (not PAS 110)	19 06 03, 19 06 04, 19 06 05, 19 06 06	68,859 t	*Separated Fibre digestates (all types):* major and secondary nutrients (N, P, K, Mg, S) and organic matter.	*Separated Fibre digestates (all types):* Potential presence of human, animal and plant pathogens and weed seeds, dependent on whether pasteurised.		
Digestate, fibre (not PAS 110)	19 06 04, 19 06 06	67,867 t				
Digestate, liquor (not PAS 110)	19 06 03, 19 06 04, 19 06 05, 19 06 06	284,208 t				
Digestate from industrial AD						
Total digestate produced		7,490,964 t				
Digestate, whole (all was waste)	19 06 03, 19 06 04, 19 06 05, 19 06 06	2,607,578 t				
Digestate, fibre (all was waste)	19 06 04, 19 06 06	125,232 t				
Digestate, liquor (all was waste)	19 06 03, 19 06 04, 19 06 05, 19 06 06	4,758,153 t				

[1]Production tonnages were from 2017 (ZWS (2019a). They do not include digestate from sewage treatment works, which is included in Section 3.4 Sewage sludge). Tonnage obtained for industrial AD plants is an estimate (ZWS, 2019a) obtained from grossing up tonnages from industrial plants which responded to the request for data. [2]In 2017, most digestate (particularly that from industrial AD plants) was discharged to water treatment, rivers and seas and was not applied to land. [3]Information on agricultural benefit was obtained from SRUC 2019; [4]Potential risks were assessed and interpreted in WRAP (2017a). [5]Data on location of digestate producers was from the UK Biofertiliser Certification Scheme website. [6]Information on landbank was based on project team knowledge of the Scottish AD sector.

Table 2.4. Distillery and other drinks wastes

In this case, the category does not include digestates. Can be applied under Para 7 only (see Section 2.4).

				Total tonnage to land (all types in 2017) 459,546 t (↑ by 11% on 2016)[1]		
Material type	**Relevant waste codes**	**No. of wet tonnes applied to land in Scotland (2017)**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets**	**Summary of geographical location of landbank**
Drinks processing wastes including distillery and brewery wastes (alcoholic and non-alcoholic other than tea, coffee, cocoa)	02 07 02 07 01 02 07 02 02 07 99	(↓ 68% on 2016) 21,705 t (↑ 572% on 2016) 89,328 t (↓ 20% on 2016) 346,252 t (not applied 2016) 2,261 t	Variable, but usually major and secondary nutrients (N, P, K, Mg, S), sometimes high in RAN (liquids), sometimes organic matter (solids).Some materials contain high concentrations of Cu and /or Zn.	Variable, therefore risks should be assessed based on interpretation of lab test results. Distillery wastes often have high Cu and Zn content. Some have high salt content. Some have high RAN content and therefore the potential for losses through ammonia volatilisation or nitrate leaching. High chemical and biological oxygen demand.	Material has originated widely across Scotland in in at least 19 local authority areas. (link to map in Objective 2).	Not known, although it is thought that most bulky materials tend to be spread in the local authority area in which they were produced (A. Cundill, pers, comm.)
[1]Figures on tonnage to land and the location of applications were based on waste return data that operators have to provide to SEPA. Most distillery and other drinks wastes are liquids which contain relatively low concentrations of plant nutrients in varying amounts. [2]Chemical composition will vary, but typical values are available in SRUC (2019). The chemical composition could also be obtained from the certificates of agricultural benefit attached to specific applications for paragraph 7 exemptions.						

Table 2.5. Composts [other than mushroom compost]

(See Section 2.5).

			Total tonnage produced (all types in 2017) 224,925 t (↑ by 20% on 2014)[1]			
Material type	**Relevant waste codes**	**No. of wet tonnes produced in Scotland (2017)**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets (all types)**	**Summary of geographical location of landbank (all types)**
Compost, green and food/green (PAS 100)	Non-waste	~ 83% or 186,688 t of all compost produced in Scotland in 2017 was PAS 100-accredited. (No comparable figures for 2014)	Major and secondary nutrients (particularly P, K, Mg, S) and organic matter. Some materials have a neutralising value.	Some composts contain physical contaminants (glass, plastic, metal and stones) though this is controlled to an extent by PAS 100. Off-specification composts are more problematic. Some (particularly immature green composts) can have undesirably high C:N ratio (these composts lock up N in soils).	There were 24 major composting sites operating under PPC permits or Waste Management Licences in 2017. Most are located in the central belt in Scotland, with one in Inverness, three in Aberdeenshire and one in the borders. There were also 126 active Paragraph 12 exemption sites. PAS100-accredited sites are mapped in Figure 7.15)	Most compost tends to be spread within a 30 mile radius of the production site (PS), but the author knows of cases where compost is applied up to 190 km from the PS where empty lorries are travelling back to base (and ready markets) from positions near to the PS.
Compost, green and food/green (off spec.)	19 05 03	~ 17% or 38,237 t of all compost produced in Scotland in 2017 was off-specification (i.e. not PAS 100-accredited). (No comparable figures for 2014)	"	"		
[1]Production tonnages taken from ZWS (2019b and 2016). Tonnages quoted do not include compost from sites operating under Paragraph 12 exemptions (likely to be around 1,200 t/year, based on unpublished SEPA information).There was no information which distinguished between green and food/green composts, though based on the percentage of input tonnages treated through outdoor windrows versus in vessel systems, for 2017, food/green composts are likely to account for ~ 43% (96,718 t) of the composts produced and green composts ~ 57% (128,207 t). The figures for PAS 100 and non-waste composts were calculated from ZWS (2019b). Of the tonnage produced in 2017, 84 to 97% went to land and 4 to 16% was used to produce growing media, bagged products or it's end use was unrecorded (ZWS, 2019b). [2]Information on agricultural benefit from SRUC 2019; [3]Data on location of compost producers was from the UK Compost Certification Scheme website (www.qualitycompost.org.uk/); [4]Information on landbank was based on the author's knowledge of the Scottish composting sector.						

Table 2.6. Sewage sludge materials regulated under Sludge (Use in Ag.) Regs. or Waste Management Licensing Regs.
(See Section 2.6).

			Total tonnage of sewage sludge produced in Scotland and applied to land (all types in 2018/19) 221,214 t[1] (↑ by 19% on 2017/18)			
Material type	**Relevant waste codes**	**No. of wet tonnes produced in Scotland (2017/18) and 2018/19**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets[3]**	**Summary of geographical location of landbank[3]**
Biosolids, enhanced treated pellets	19 08 05 (code applies only if material is applied under Waste Management Licensing Regulations in a Paragraph 8 or 9(1) exemption. Treated sewage sludge applied under Sludge (Use in Agriculture) Regulations is not regulated as waste.	(20,159) 42,021 t	Major and secondary nutrients (particularly P with some K & Mg, S).	*Treated and enhanced treated sewage sludge (biosolids):* can have high PTE concentrations; some concern about the presence of 'emerging' contaminants (e.g. microplastics, pharmaceuticals, industrial chemicals and nanoparticles). High chemical and biological oxygen demand. *Untreated sewage sludge:* As above. Contain high numbers of human and animal pathogens including E. coli, Salmonella and other intestinal pathogens. High chemical and biological oxygen demand.	Sewage treatment works are located throughout Scotland. The locations of all of them are known and mapped (Figures 7.9 and 7.10).	Treated sewage sludge (spread under the Sludge (Use in Agriculture) Regulations is typically spread within a 30 km radius of sewage treatment plants, though the distances may be longer when landbank is scarce (e.g. around Glasgow). Pellets, which are lighter in relation to their fertiliser nutrient content may be transported further. Liquid sludges are typically transported distances of less than 12 km. Untreated sewage sludge is spread under Paragraph 9 (1) exemptions at land restoration sites. Currently these are only operational in Ayrshire, but in the past, sites in Fife and North/ South Lanarkshire have also been used.
Biosolids, enhanced treated cake	"	(82,243) 52,377 t	Major and secondary nutrients (particularly readily available N, and P), in some cases liming value.			
Biosolids, conventionally treated liquid	"	(7,636) 9,200 t	Major and secondary nutrients (particularly P, N & S).			
Biosolids, conventionally treated cake	"	(13,193) 12,721 t	Major and secondary nutrients (particularly N, P, S), organic matter. In some cases liming value.			
Sewage sludge, untreated or non-compliant with standards for conventionally treated sludge	"	(62,215) 104,895 t	Major and secondary nutrients (particularly N, P, S), organic matter, in some cases liming value.			

[1]Figures on tonnage to land based on unpublished information provided by Scottish Water. Sewage sludge sent to "Energy from Waste or landfill is not included. Sewage sludge from England and Northern Ireland are also known to be spread in Scotland, but it has not been possible to determine the tonnages involved, or where they are spread. Further details are provided in Section 3.4. [2]Information on agricultural benefit from SRUC 2019; [3]Data on outlets and landbank based on unpublished information provided by Scottish Water.

Table 2.7. Wastes from pulp, paper and card production and processing

These particular "03 03" waste codes can be applied under a Para 7 only (see Section 2.7).

			Total tonnage to land (all types in 2017) 24,109 t[1] (↓ by 19% on 2016)			
Material type	**Relevant waste codes**	**No. of wet tonnes applied to land in Scotland (2017)**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets**	**Summary of geographical location of landbank**
Waste bark and wood	03 03 01	(↓ 64% on 2016) 1,765 t	Variable depending on treatment method. Often high C:N ratio (potential to lock up N), organic matter. May contain major and secondary nutrients (particularly P, S, Mg), but these nutrients are usually only slowly available. Some materials also have a liming value.	High C:N ratio, which can result in N lock up when material is applied to soils.	(All pulp, paper and card wastes) - remaining paper mills are in Fife and Aberdeenshire.	Most paper wastes are spread in Aberdeenshire and Fife, where the paper mills are known to exist (A. Cundill, pers. comm.).
Sludges from on-site effluent treatment plants (virgin pulp, no inks)	03 03 11	(↓ 89% on 2016) 945 t	"	"		
De-inked sludge from paper recycling and ink-free paper crumble from virgin pulp	03 03 99	(↑ 32% on 2016) 21,390 t	"	"		
[1]Figures on tonnage to land and the location of applications were based on waste return data that operators have to provide to SEPA. [2]Most pulp paper and card wastes are stackable solids which are applied mainly as an organic matter source with a high C:N ratio. Some types also contain useful concentrations of plant nutrients. Chemical composition will vary to a limited extent; typical values are available in SRUC (2019). Details of agriculturally beneficial and some other parameters could also be obtained from the certificates of agricultural benefit attached to specific applications for paragraph 7 exemptions.						

Table 2.8. Non-meat food wastes

Can be applied under Para 7 only (see Section 2.8).

			Total tonnage to land (all types in 2017) 23,264 t[1] (↓ by 53% on 2016)			
Material type	**Relevant waste codes**	**No. of wet tonnes applied to land in Scotland (2017)**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets**	**Summary of geographical location of landbank**
Wastes from preparation/processing of non-meat foods (e.g. veg, fruit, cereals, oils, cocoa, tea, coffee). Includes:	02 03	(↓89% on 2016) 1,500 t	Most materials are liquids which contain variable amounts of major and secondary nutrients (N, P, K, Mg, S). Some of these liquids contain high concentrations of RAN. Some solid materials contain useful amounts of organic matter. Some (e.g. mushroom compost) have high liming value.	Variable, therefore risks should be assessed based on interpretation of lab test results. Some materials have high salt content, high chemical and biological oxygen demand. Some have high RAN content and therefore the potential for losses through ammonia volatilisation or nitrate leaching.	Material has originated mainly in Aberdeenshire, East Lothian and the borders, but some has originated from unrecorded locations.	Not known, although it is thought that most bulky materials tend to be spread in the local authority area in which they were produced, hence most is likely to have been spread in Aberdeenshire, East Lothian and the borders. (A. Cundill, pers, comm.). The author is aware that most Scottish mushroom compost is spread in East Lothian, probably in close proximity to a mushroom producer located there.
• sludges from washing, cleaning, peeling, centrifugation, separation (and mushroom composts)	02 03 01	(↓18% on 2016) 7,813 t				
• wastes from preserving agents	02 03 02	(not applied 2016) 10,300 t				
• materials unsuitable for consumption or processing	02 03 04	(22,923 t in 2016) 0 t				
• sludges from on-site effluent treatment	02 03 05	(500 t in 2016) 0 t				
• dairy wastes unsuitable for consumption or processing	02 05 01	(not applied 2016) 1,101 t				
• bakery and confectionary wastes (sludges from on-site effluent treatment	02 06 03	(↓14% on 2016) 2,550 t				

[1]Figures on tonnage to land and the location of applications were based on waste return data that operators have to provide to SEPA. [2]Representative values for chemical and physical properties of liquid materials in this category, plus mushroom compost are published in SRUC (2013). However, properties are likely to vary widely. If further detail is required, study of individual certificates of agricultural benefit associated with applications for paragraph 7 exemptions would be required.

Table 2.9. Meat, fish and animal origin food wastes
Can be applied under Para 7 only (see Section 2.9).

			Total tonnage to land (all types in 2017) 18,254 t[1] (↓ by 36% on 2016)			
Material type	**Relevant waste codes**	**No. of wet tonnes applied to land in Scotland (2017)**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets**	**Summary of geographical location of landbank**
Wastes from preparation/processing of meat, fish and other foods of animal origin (e.g. abattoir wastes) but unsuitable for consumption or processing.	02 02 03	18,254 t (as above, only one waste code in this group)	Some materials are liquids which contain variable amounts of major and secondary nutrients (N, P, K, Mg, S). Some of these liquids contain high concentrations of RAN. Some solids, such as gut contents contain useful amounts of organic matter.	Variable, therefore risks should be assessed based on interpretation of lab test results. Some materials have high salt content, high chemical and biological oxygen demand. Some have high RAN content and therefore the potential for losses through ammonia volatilisation or nitrate leaching. Some can contain human and animal pathogens (e.g. *E. coli* and *salmonella* species)	Material has originated in a few local authority areas, mainly including Aberdeenshire, North Ayrshire, Perth and Kinross, Scottish Borders, but some has originated from unrecorded locations.	Not known, although it is thought that most bulky materials tend to be spread in the local authority area in which they were produced (A. Cundill, pers, comm.).
[1]Figures on tonnage to land and the location of applications were based on waste return data that operators have to provide to SEPA. [2]No representative values for chemical and physical properties of materials in this category have been published and properties are likely to vary widely. If further detail is required, study of individual certificates of agricultural benefit associated with applications for paragraph 7 exemptions would be required.						

Table 2.10. Clean water treatment sludge
Can be applied under Para 7 or Para 9 (see Section 2.10).

			Total tonnage to land (all types in 2018/19) 29,173 t[1] (↓ by 11% on 2017/18)			
Material type	**Relevant waste codes**	**No. of wet tonnes applied to land in Scotland (2018/19)**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets**	**Summary of geographical location of landbank**
Wastes from preparation of water for human consumption or industrial uses (sludges from water clarification)	19 09 02 (para 7) 19 09 02 (para 9)	(↓ 32% on 2017/18) 1,291 t (↓ 10% on 2017/18) 27,168 t	High C:N ratio (potential to lock up N), organic matter.	High aluminium content in sludges from most treatment works, therefore potential to lock up soil P (though the extent to which this happens in practice is unknown).	Material has come from widely across Scotland (from 16 local authority areas).	It is thought that the small amount of material spread under Paragraph 7 exemptions will have been spread in the local authority area in which they were produced (A. Cundill, pers. comm.). However, material spread under Paragraph 9 exemptions will most likely have been spread on brownfield restoration land in Ayrshire, Fife, North and South Lanarkshire (where most of this type of land is). Scottish Water plan in future to apply this material to agricultural land where possible, since they are aware that the area of brownfield land needing restored is decreasing all the time.
[1]Figures on tonnage to land and the location of applications were based on waste return data that operators have to provide to SEPA. [2]Values for chemical and physical properties of materials in this category were from Rollet *et al.,* 2015). Scottish Water have not yet provided further analytical data for materials applied in Scotland.						

Table 2.11. Plant tissue wastes

Can be applied under Para 7 only (see Section 2.11).

			Total tonnage to land (all types in 2017) 12,140 t[1] (↑ 24% on 2016)			
Material type	**Relevant waste codes**	**No. of wet tonnes applied to land in Scotland (2017)**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets**	**Summary of geographical location of landbank**
Plant tissue wastes	02 01 03	12,140 t (as above, only one waste code in this group)	Variable, but mainly major and secondary nutrients (particularly N, P, S, Mg).	Variable, therefore risks should be assessed based on interpretation of lab test results. Some materials may contain plant pathogens.	Material has originated in a few local authority areas, mainly City of Edinburgh and Dumfries and Galloway, but for much of it, the origin is unrecorded.	Not known, although most bulky materials tend to be spread in the local authority area in which they were produced (A. Cundill, pers, comm.).

[1]Figures on tonnage to land and the location of applications were based on waste return data that operators have to provide to SEPA. [2]No representative values for chemical and physical properties of materials in this category have been published and properties are likely to vary widely. If further detail is required, study of individual certificates of agricultural benefit associated with applications for paragraph 7 exemptions would be required.

Table 2.12. Waste ash

Can be applied under Para's 7, 9 or 50 (see Section 2.12).

			Total tonnage to land (all types in 2017) 10,237 t[1] (↑ 40% on 2016)			
Material type	**Relevant waste codes**	**No. of wet tonnes applied to land in Scotland (2017)**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets**	**Summary of geographical location of landbank**
Bottom ash from combustion of biomass Pulverised fuel ash Fly ash from peat and untreated wood	10 01 01 (para 7) 10 01 01 (para 50) 10 01 02 (para 9) 10 01 03 (para 7) 10 01 03 (para 9)	(↑426% on 2016) 3,944 t (same in 2016) 1,200 t (same 2016, 2017) 750 t (↓1% on 2016) 4,343 t not applied 2016 or 2017	Variable, but mainly major nutrients P and K. Can also have a strong neutralising value (which can be a risk if material is applied to high pH soils).	High concentrations of some PTEs in some materials. High neutralising value (can be a benefit in low pH soils). Expert interpretation of lab test data of individual materials is essential.	Some was from Highland region, and a further major source is in Moray. The origin of the majority of the material was unrecorded, but some is known to have come from Cumbria (A. Cundill, pers. comm.).	It is known that some material was applied in Moray and Highland regions. It is also known that that from the paperboard factory in Cumbria is spread mainly in Dumfries and Galloway (A. Cundill, pers. comm.). It is not known where the rest was spread. Due to its light weight, it may be economic to transport it further than with many waste types such as FYM.

[1]Figures on tonnage to land and the location of applications were based on waste return data that operators have to provide to SEPA. [2]No representative values for chemical and physical properties of materials in this category have been published and properties are likely to vary widely. If further detail is required, study of individual certificates of agricultural benefit associated with applications for paragraph 7 exemptions would be required.

Table 2.13. Wastes from wood processing
Can be applied under Para 7 only (see Section 2.13).

			Total tonnage to land (all types in 2017) 1,906 t[1] (↑ by 31% on 2016)			
Material type	**Relevant waste codes**	**No. of wet tonnes applied to land in Scotland (2017)**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets**	**Summary of geographical location of landbank**
Wood wastes	03 01 01 03 01 05	not applied 2016 or 2017 (↑ 31% on 2016) 1,906 t	Variable. Often high C:N ratio (potential to lock up N), organic matter (can be a risk in some cases). Likely to contain major and secondary nutrients (particularly P, K, Mg).	Variable. Often high C:N ratio (potential to lock up N), organic matter (can be a benefit in some cases).Can contain high PTE concentrations, especially Zn.	The only material recorded has come from Highland Region from a single supplier (A. Cundill, pers. comm.).	It is known that all of this material has been applied to farmland near Inverness (Highland Region) under Paragraph 7 exemptions (A. Cundill, pers. comm.)
[1]Figures on tonnage to land and the location of applications were based on waste return data that operators have to provide to SEPA. [2]No representative values for chemical and physical properties of materials in this category have been published. If further detail is required, study of individual certificates of agricultural benefit associated with applications for paragraph 7 exemptions would be required.						

Table 2.14. Wastes from chemical production including all types of waste gypsum
Can be applied under Para 7 or 9 (see Section 2.14).

			Total tonnage to land (all types in 2017) 762 t[1] (↓ by 60% on 2016)			
Material type	**Relevant waste codes**	**No. of wet tonnes applied to land in Scotland (2017)**	**Key agricultural benefits[2]**	**Potential risks**	**Summary of geographical location of outlets**	**Summary of geographical location of landbank**
Sludges from on-site effluent treatment (not containing dangerous substances) Gypsum	07 07 12 (para 7) 07 07 12 (para 9) 06 01 99 (para 7) 10 01 99 (para 7) 10 13 04 (para 7)	(970 t in 2016) 0 t in 2017 (↓ 19% on 2016) 762 t 2016 and 2017 0 t 2016 and 2017 0 t (↓55% on 2016) 400 t	Variable, but usually specific plant nutrients. In the case of gypsum, it's a source of Ca and S.	Variable. The extent to which these types of wastes contain PTEs or other undesirable contaminants will depend on the process. Expert interpretation of lab test data of individual materials is essential.	Material has originated in the borders and in an unknown location, possibly Ayrshire (under Para 7s) and in North Ayrshire (under a Para 9).	Not known, although it is thought that there was a factory in N. Ayrshire producing a calcium-sulphate-based waste which may mainly have gone to land locally. It is also thought that production of this material has ceased (A. Cundill, pers. comm.)
[1]Figures on tonnage to land and the location of applications were based on waste return data that operators have to provide to SEPA. [2]There is no available information on agricultural benefit, which will vary depending on the production process. It could be obtained from the certificates of agricultural benefit attached to specific applications for paragraph 7 or 9 exemptions.						

2.2 Animal manures and slurries

Tonnages produced annually

The quantities of livestock slurries and manures presented in Tables 2.16 and 2.17 were calculated by SAC Consulting based on the data described in A – E below:

A. Livestock numbers in Scotland by age class, species and type.
National totals of animal numbers were obtained for each year from the Scottish Government's June Agricultural Census (Scottish Government, 2019; 2018b; 2015). A breakdown of animal numbers by Scottish Local Authority area was obtained for 2015 as part of a project for Zero Waste Scotland (ZWS, 2017). Some of the livestock data was disclosive (there were fewer than five reported holdings within any one Local Authority area) and cannot be published but resides within the SAC Livestock manure model. Given time constraints and the understanding that little change in livestock distribution will have occurred in the four years to 2019, seeking more recent data would have added significant delay to the study with limited benefit. Also, this data matches the date (2015) of the data used in the GIS assessment. For the purposes of this project the regional livestock distribution pattern from 2015 has been adjusted pro-rata in line with changes in the national June Census totals.

B. Manure and slurry livestock daily excretion rates per head.
These were obtained for the different livestock classes and livestock systems from Farm Management Handbook (SRDP Farm Advisory Service, 2019) and Scottish Government's "Guidance for farmers in Nitrate Vulnerable Zones" (Scottish Government, 2016a).

C. Regional variations in housing method and duration.
SAC Consulting prepared estimates of the proportion of time in the year (weeks) that each livestock type and age class spends on the main housing type (slatted or solid) or outside. These are based on a 2016 survey of SAC's agricultural consultants in 23 regional offices across Scotland. SAC staff prepared their estimates drawing on typical farm records for their area prepared for Nutrient Management Plans using PLANET Scotland (PLANET, no date).

D. Straw and bedding inclusion in solid manures.
Estimates of straw bedding use per head per day were obtained from T. Misselbrook (pers. comm.) and were based on unpublished manure management data used in the 2016 UK National Greenhouse Gas Inventory. Straw conversion factors (to estimate the additional material added to livestock excreta from the inclusion of straw) were obtained from the Scottish Government's "Guidance for farmers in Nitrate Vulnerable Zones" (Scottish Government, 2016a)

E. Total estimates of manures and slurries.
For slurries, estimates were derived by multiplying the number of livestock (of specific age and type on a particular system) by their daily slurry excretions and the numbers of days housed. Any dilution to the slurries is built into the estimates obtained from SRDP Farm Advisory Service (2019, see B above and Table 2.15).

For manures, estimates were derived by multiplying the number of livestock (of specific age and type) by their daily excretions and daily straw use (for bedding) per head and the number of days housed, taking into account the straw conversion factor (SRDP Farm Advisory Service, 2019; see B above).

Table 2.15: Typical dry matter content used when calculating estimates of livestock excretion volumes (ADAS, 2007)

Manure Type	Dry Matter DM (%)
Dairy Cattle Slurry	7.8
Beef Cattle Slurry	8.7
Cattle Slurry[1]	8.5
Pig Slurry	3.7
Layer Manure	35
Poultry litter	60
[1]"conventional cattle slurry collected from mixed beef and dairy units	

Table 2.16. Historic estimates of the amount of manure and slurry (in 000s of tonnes) being applied to land in Scotland

	Year						**Change (%) in 2019 since:**	
Manure type	**2010**	**2015**	**2016**	**2017**	**2018**	**2019**	**2015**	**2010**
Solid manure	6,271	5,899	5,919	5,858	5,769	5,695	-3%	-9%
Liquid slurry	5,772	5,980	5,965	5,900	5,799	5,735	-4%	-1%
Total (livestock manures)	**12,043**	**11,879**	**11,884**	**11,758**	**11,567**	**11,430**	-4%	-5%
Solid dairy manure	324	392	388	384	378	374	-5%	15%
Solid beef cattle manure	5,118	4,779	4,776	4,715	4,654	4,575	-4%	-11%
Total (Solid cattle manures)	**5,443**	**5,171**	**5,164**	**5,099**	**5,032**	**4,949**	-4%	-9%
Total (solid pig manures)	**348**	**265**	**279**	**274**	**265**	**272**	**3%**	**-22%**
Total (solid sheep manures)	**375**	**370**	**375**	**382**	**365**	**367**	**-1%**	**-2%**
Layers & breed hens	41	47	53	56	57	61	29%	51%
Broilers & other poultry	64	46	48	46	51	45	-2%	-29%
Total (Poultry manures)	**105**	**94**	**101**	**103**	**107**	**107**	**14%**	**2%**
Cattle slurry (dairy)	2,494	2,995	2,963	2,934	2,884	2,853	-5%	14%
Cattle slurry (beef)	2,748	2,568	2,567	2,535	2,500	2,459	-4%	-11%
Total (cattle slurries)	**5,243**	**5,563**	**5,530**	**5,469**	**5,384**	**5,312**	**-5%**	**1%**
Total (pig slurries)	**469**	**357**	**374**	**369**	**355**	**364**	**2%**	**-22%**
Total (sheep slurries)	**61**	**60**	**60**	**62**	**59**	**59**	**0%**	**-2%**

Historical trends and future projections

Based on changes in livestock numbers alone, SAC Consulting estimate that the total volume of livestock manures produced in Scotland has declined by 5% between 2010 and 2019 and by 4% since 2015. Some sectors have seen greater estimated declines such as pigs and beef cattle while others have increased such as dairy and layers; details in Table 2.16.

The present time is one of unprecedented uncertainty (since WWII) for UK agriculture due to the UK's exit from the European Union, which is expected to have a fundamental impact on agricultural trade, regulation, labour availability and public support. Reliably forecasting how these changes may affect livestock numbers in Scotland and resulting manure output is not possible. Instead in this study, a two-part approach has been taken. Firstly, a continuation of recent historic trends (10 years to 2019) in livestock numbers has been extrapolated using logarithmic trends through the future projection period. This represents a continuation of the status quo. Secondly, two contrasting scenarios (one positive, one negative for livestock numbers) have been selected from the most up to date agricultural sector EU exit forecasts for Scotland as prepared by FAPRI UK (AFBI, 2017). The impact of the three possible scenarios on annual tonnages of manures and slurries produced is discussed below and is summarised in Table 2.17.

Scenario 1: Historic 10-year trend projections
This represents continuation of the status quo. This would result in a 2% (0.2 Mt) reduction from 2019 in total manures produced to 11.2 Mt by 2039. Within this total, declines would be seen in the tonnage of manures produced in the beef cattle, pig, and broiler chicken sectors and increases in the amount of manures produced from dairy cattle and laying hens.

Scenario 2: FAPRI-UK Fortress UK (WTO+DP) (S5)
This would involve implementation of EU levels of import protection and continuation of current direct support levels to agriculture. This would favour increased output from the UK livestock sector. It would result in a 17% (1.9 Mt) increase from 2019 in total manures produced to 13.3 Mt by 2034/39. Within this total, declines would be seen in the tonnage of manures produced in the beef cattle, pig, and broiler chicken sectors and increases in the tonnage of manures from dairy cattle and laying hens. The FAPRI-UK study did not include any assessments of changes in livestock on a regional basis within Scotland. Further work to assess regional changes in livestock numbers is out with the scope and time constraints of this study.

Scenario 3: FAPRI-UK Freetrade UK (UTL-DP) (S4)
This would involve unilateral removal of all import protection and elimination of all direct support to agriculture. This would result in a 30% (3.4 Mt) decrease from 2019 in total manures produced to 8.0 Mt by 2034/39. Within this total, livestock numbers in all sectors would fall, led by sharp declines in beef production, while the most intensive sectors; dairy, pigs and poultry would likely see only modest declines. The FAPRI-UK study did not include any assessments of changes in livestock on a regional basis within Scotland. Further work to assess regional changes in livestock numbers is out with the scope and time constraints of this study.

It is not possible to make a judgement on which of the above scenarios is more or less likely at this stage, given that almost any scenario remains a feasible outcome under Brexit.

Table 2.17. Future projections (in 000s of tonnes) of manure and slurry being applied to land in Scotland under proposed scenarios 1, 2 and 3

	Scenario 1 - Historic 10 year (logarithmic livestock numbers)				Scenario 2 - FAPRI-UK Fortress UK (WTO+DP) (S5)			Scenario 3- FAPRI-UK Freetrade UK (UTL-DP) (S4)		
	Year				Year			Year		
Manure type	**2024**	**2029**	**2034**	**2039**	**2024**	**2029**	**2034/39**	**2024**	**2029**	**2034/39**
Solid manure	5,699	5,633	5,583	5,542	6,257	6,745	6,745	4,556	3,418	3,418
Liquid slurry	5,711	5,687	5,668	5,654	6,201	6,603	6,603	5,167	4,599	4,599
Total (livestock manures)	**11,410**	**11,320**	**11,251**	**11,196**	**12,458**	**13,348**	**13,348**	**9,724**	**8,017**	**8,017**
Solid dairy manure	374	376	378	379	393	408	408	380	385	385
Solid beef manure	4,612	4,552	4,507	4,470	5,096	5,538	5,538	3,454	2,333	2,333
Total cattle manure	**4,985**	**4,928**	**4,884**	**4,849**	**5,489**	**5,946**	**5,946**	**3,834**	**2,718**	**2,718**
Total (solid pig manures)	**241**	**234**	**228**	**224**	**303**	**342**	**342**	**268**	**264**	**264**
Total (solid sheep manures)	**367**	**365**	**364**	**362**	**352**	**339**	**339**	**349**	**330**	**330**
Layers & breed hens	60	63	66	68	60	62	62	61	61	61
Broilers/other poultry	45	42	41	39	53	56	56	45	45	45
Total poultry manures	**105**	**106**	**106**	**107**	**113**	**118**	**118**	**106**	**106**	**106**
Cattle slurry (dairy)	2,851	2,868	2,882	2,893	2,999	3,115	3,115	2,896	2,939	2,939
Cattle slurry (beef)	2,479	2,447	2,422	2,402	2,738	2,976	2,976	1,857	1,254	1,254
Cattle slurry total	**5,329**	**5,314**	**5,304**	**5,296**	**5,737**	**6,090**	**6,090**	**4,753**	**4,193**	**4,193**
Pig slurry (liquid)	**323**	**313**	**305**	**299**	**407**	**458**	**458**	**358**	**353**	**353**
Sheep slurry (liquid)	**59**	**59**	**59**	**59**	**57**	**55**	**55**	**56**	**53**	**53**

Benefits and risks from the use of animal manures and slurries

Very few applications of animal manures and slurries are made to amenity or restoration land since most farmers value their manures and apply them on their own farm or sell them locally to other farmers. The exception is poultry manures, which often travel as the local landbank does not need the nutrients and because transport is likely to be more economical than for other animal manures, due to the high nutrient content per unit weight.

Animal slurries are generally good liquid fertilisers which are applied for their nutrient content, particularly N, P, K, Mg and S (Table 2.18). They almost always have a high RAN content and for that reason, they should be stored, handled and spread with great care in order to minimise the potential for N losses. Pig slurries are the most nutrient-rich animal slurries, with the highest RAN content. Slurries are fertilisers first and foremost. Although they contain organic matter, they mainly contain water. Animal slurries are not typically applied at sufficient rates with enough frequency to make significant additions of organic matter to soils. Solid animal manures are both useful fertilisers and soil conditioners which are applied for their organic matter content and their nutrient content, particularly N, P, K, Mg and S (Table 2.18).

Table 2.18. Typical dry matter (DM) and nutrient contents of livestock manures (FYM) and slurries

Manure type	DM (%)		kg/fresh t (solid manures) or kg/m^3 (liquids/slurries)				
		% RAN content	Total N	Total P_2O_5	Total K_2O	Total SO_3	Total MgO
Cattle FYM – fresh	25	1.2	6.0	3.2	8.0	2.4	1.8
Cattle FYM – old	25	0.6	6.0	3.2	8.0	2.4	1.8
Pig FYM – fresh	25	1.8	7.0	6.0	8.0	3.4	1.8
Pig FYM – old	25	1.0	7.0	6.0	8.0	3.4	1.8
Sheep FYM – fresh	25	1.4	7.0	3.2	8.0	3.0	1.6
Sheep FYM – old	25	0.7	7.0	3.2	8.0	3.0	1.6
Duck FYM – fresh	25	1.6	6.5	5.5	7.5	2.6	1.2
Duck FYM – old	25	1.0	6.5	5.5	7.5	2.6	1.2
Layer manure	35	9.5	19.0	14	9.5	4.0	2.6
Broiler / Turkey litter	60	10.5	30.0	25	18	8.0	4.4
Horse FYM	30	0.7	7.0	5.0	6.0	*	*
Goat FYM	25	0.6	6.0	3.2	8.0	2.4	1.8
Cattle slurry	6	1.2	2.6	1.2	3.2	0.7	0.6
Pig slurry	4	2.5	3.6	1.8	2.4	1.0	0.7
Cattle slurry, strainer box liquid	1.5	0.8	1.5	0.3	2.2	N/A	N/A
Cattle slurry, weeping wall liquid	3	1.0	2.0	0.5	3.0	N/A	N/A
Cattle slurry, mechanically separated liquid	4	1.5	3.0	1.2	3.5	N/A	N/A
Cattle slurry, separated solids	20	1.0	4.0	2.0	4.0	N/A	N/A
Pig slurry, separated liquid	3	2.2	3.6	1.6	2.4	N/A	N/A
Pig slurry, separated solids	20	1.3	5.0	4.6	2.2	N/A	N/A
Dirty water	0.5	0.3	0.5	0.1	1.0	0.1	0.1
Source: SRUC (2013); N/A = data not available							

The benefits and risks associated with applying animal manures and slurries to land have been studied, quantified and discussed in relation to those of other organic materials in several recent publications including Cundill *et al.,* 2012; WCA Environment (2014; 2019) and WRAP (2016; 2017a; 2017b). Due to the very high tonnages of animal manures and slurries which are applied to land in Scotland in comparison with all other materials (over 86% of the total of all materials applied), a comprehensive understanding of the benefits and risks associated with applying them is of the utmost importance. The main risks include:

- accumulation of PTEs (especially Cu and Zn) in soils following application of manures/slurries of intensively fed animals)
- the presence of organic contaminants, in particular veterinary medicines in manures/slurries
- the over-application of nutrients following repeated and/or excessive applications of manures/slurries
- the spread and persistence of animal pathogens (including those resistant to antimicrobial drugs) in manure/slurry-treated soils and crops
- odour and air quality issues when handling slurries and manures and following slurry/manure applications
- anaerobic conditions in soils and the risk of increased nitrous oxide and methane emissions following application of manures and slurries (particularly slurries) in some conditions (particularly warm conditions following wet weather, when the soil is gradually drying out).

It is important to note that most of the above risks are well understood, as are the measures which farmers can take to minimise them and maximise the benefits from spreading manures and slurries on their land. Further study is required to determine the extent of the problems of organic contaminants such as veterinary medicines in animal manures and associations between spreading these to land and the development of antimicrobial resistance.

2.3 Anaerobic digestates

Tonnages produced annually

There are approximately 53 anaerobic digestion (AD) plants in Scotland (not including those treating waste water (sewage sludge) (Section 3.4.3 and Figure 7.13). This is an increase from 43 plants in 2017. Eleven of these plants are PAS110-accredited. For the purposes of this project, AD plants have been classified into three types as in ZWS 2019a. Merchant AD plants are defined as those which accept wastes from off-site, on a commercial basis (i.e. for a gate fee). These can include farm-based enterprises. Industrial AD plants are those which process their own by-products, typically on a large scale, such as food and drink manufacturers. Farm-based AD plants are located on a farm and process only material generated on that farm (such as energy crops, crop residues and livestock slurries).

There was 8,159,575 t of anaerobic digestate produced in Scotland in 2017, not including 599,524 t produced at waste water treatment (sewage) works, which have been included in Section 3.4.1 Sewage sludge (ZWS, 2019a) (Table 2.3). Of the 8,159,575 t, 3 % (250,676 t) were produced at merchant AD plants, 5% (417,935 t) at farm-based AD plants and 92 % (7,490,964 t) at industrial AD plants. The authors of the ZWS (2019a) report drew attention to the fact that the total figure for digestate produced at industrial AD plants was an estimate based on grossed up production figures from three out of the total of seven plants in existence at the time. The total tonnage will have differed from that reported, but without doubt it would still have been very much greater than that produced at merchant and farm-based plants.

When looking at the tonnages of digestate produced across Scotland, and the required landbank, it is important to consider fibre digestates separately from liquor and whole digestates. Most fibre digestates contain sufficient dry matter that they can stack safely and most contain < 30% RAN. They generally contain nutrients in a less-available form than liquids and whole digestates, and leaching and volatilisation of nutrients is not usually a serious risk, provided they are handled, stored and spread sensibly. Whole and liquor digestates are very different. They are usually excellent fertilisers which contain high concentrations of RAN and other readily available nutrients. However, they are heavy in relation to their nutrient content (costly to transport) and the potential for significant N losses is high where they are stored inappropriately, applied at inappropriate times of year, applied using old splash-plate slurry systems or when weather and soil conditions are poor. There is certainly considerable potential to improve N use efficiency and to reduce N losses from better use of digestates across Scotland.

There is a clear need to obtain more recent data on the actual tonnages of the different types of digestate currently being applied to land in Scotland, since the total tonnage produced from AD is high and since the number and size of AD plants has changed since the last published figures were produced. There are likely to be over 8 million tonnes produced annually in future (most of it from industrial AD), although in 2017, the great majority of that was discharged to sewer, river or sea (Table 2.19). Of over 8 million tonnes of digestate produced, only around 9% was spread to land in 2017 and only 2.6% of the total was PAS 110-accredited (ZWS, 2019a). The industry has matured considerably since the last data was obtained 3 years ago. Given that there are eleven PAS 110-accredited plants now (rather than the seven present in 2017), this may mean that more of the digestate produced will be being applied to land (rather than discharged to sewer or sea), but the authors have no anecdotal evidence or published reports to demonstrate that this is happening.

Table 2.19. Fate of digestates produced in Scotland in 2017 (all types excluding waste water treatment [i.e. sewage sludge])

		Amount (t) sent to		
Digestate from merchant AD	**No. of wet tonnes produced**	**Agriculture/ field horticulture**	**Other land applications (e.g. restoration, landscaping)**	**Discharged to sewer, river or sea**
Digestate, whole and liquor (PAS110/waste)	244,878 t	199,200 t	3,862 t	41,696 t
Digestate, fibre (PAS 110/waste)	5,799 t	1,095 t	4,568 t	0 t
Digestate from farm-based AD				
Digestate, whole and liquor (not PAS110)	353,067 t	350,067 t	0 t	0 t
Digestate, fibre (not PAS110)	67,867 t	67,867 t	0 t	0 t
Digestate from industrial AD				
Digestate, whole/liquor (all was waste)	7,365,731 t	0 t	0 t	7,365,731 t
Digestate, fibre (all was waste)	125,232 t	125,067 t	165 t	0 t
Production tonnages and information on the fate of digestates were from the year 2017 (ZWS (2019a). Tonnages quoted do not include digestate from sewage treatment works, which is included in Section 3.4 Sewage sludge).				

Location of AD plants and landbank

Most Scottish AD plants other than the one in the Western Isles are situated in the eastern arable areas of Scotland. There are around 15 farm-based plants situated in the south west of Scotland and a few in the Scottish Borders. There are very large areas of Scotland to the north and west of the central belt which have no AD plants.

Where digestate is spread to land, it tends to be spread within a 20 mile radius of the production site (PS) and in the case of farm-based digestates, often on the farm or local farms where purpose-grown crops have been produced. However, the author of this section knows of cases where digestate is transported routinely from west coast merchant AD plants to the east coast arable areas in order to find agricultural markets. This can involve transport distances of over 160 km (see Section 3.4.3 for location of AD plants).

Future tonnages of anaerobic digestate

It is difficult to predict future tonnages of digestate which might be applied to land in Scotland, particularly since the industry has developed so fast in the past few years, is continuing to do so and since current data on tonnages produced and their fate is out of date. There are other uncertainties within this sector, including those surrounding the future of subsidy for AD. Most AD plants are subsidy-driven and if the subsidy to AD falls substantially, then some of the AD plants (particularly the smaller ones) may cease production. In the case of food waste, it may go to dry AD or composting instead. For those farm-based plants, the farm will simply revert to producing crops for other reasons than digestate and in the case of industrial plants, the feedstocks will go to the markets that they formerly did (either direct to land or for animal feed).

Many of the larger “gas to grid” plants are likely to be economic without subsidy and will therefore continue to produce digestate, although probably with increased separation and perhaps drying of the fibre to reduce the volume of material to be transported, stored and spread. Drying will effectively concentrate the nutrients and will reduce the cost of transport, which may mean that it can be transported further cost-effectively.

There is increasing pressure to recycle organic resources rather than dump them in landfill or discharge them to watercourses/sea (now strictly regulated), but there is not yet an outright ban on landfilling organic materials. Whilst there is legislation to ensure that food-wastes are source-segregated and submitted for treatment from householders and businesses, there is still a great deal of organic material within municipal residual waste which ends up in landfill. Discussions with several local authorities suggests that some have moved away from separate food waste collections and others are considering doing so to reduce collection costs. This may mean that more food wastes are going to end up in composting or dry AD (from which composts rather than digestates are usually produced).

If the proposed ban on organic materials to landfill is brought in, particularly if it is brought in alongside a dedicated campaign to educate householders on source-segregation methods, then the tonnage of digestate available for spreading (from merchant AD) may go up, but it is unlikely, since the author’s view is that increased tonnages of food wastes are more likely to go to in-vessel composting or potentially even dry AD.

Table 2.20 shows four possible scenarios for the tonnage of digestate being applied to land in Scotland over 5, 10, 15 and 20 years. Since fibre and whole/liquor digestates are very different, they have been treated separately. The first scenario is that digestate production and tonnages to land remain the same, which seems unlikely given the recent rapid increase in the number of Scottish AD plants. The second scenario is that digestate production and tonnages to land remain the same, but that the tonnage of whole and separated liquor applied to land increases by 40% over 20 years. This might happen because increasing numbers of plants are gaining PAS 110 accreditation and the managers may therefore feel that their digestate has a financial value in agriculture. The third scenario is that digestate production increases by 20% (which it is likely to do given the recent increase in the number of Scottish AD plants) and that the tonnage of liquor and whole digestate increases by 40% as for scenario 2 (with a significant proportion of the whole and separated liquor continuing to be discharged to sewer, river and sea as it currently is). The fourth scenario is that that digestate production increases by 20% but that the tonnage of whole and separated liquor applied to land decreases by 60% over 20 years. Again, this scenario is quite possible, given the high cost of finding markets for whole and liquid digestates in some areas (see below).

Given the pressure to generate renewable energy, reduce use of finite resources, increase the recycling of organic resources and minimise methane emissions from landfill sites, it is likely that AD has a strong future. However, due to high costs of storing, transporting and applying whole and liquor digestates and the difficulties in finding reliable agricultural markets, it is likely that more and more plants will look to separate the digestate into a fibre fraction and a (ideally very) low-nutrient liquor which can be ultimately be discharged to sewer (the author is in discussion with several companies planning such measures). It is therefore likely that the tonnages of liquor and whole digestate will fall in future, and the proportion of fibre digestates sent for land application produced will increase, possibly in line with scenario 4 (Table 2.20). There is little doubt that scenario 4 could be a good thing in terms of reducing the N losses from digestate applications. It may also reduce the carbon emissions associated with hauling and spreading whole and liquor digestates.

Table 2.20. Possible scenarios for changes to the amount of fibre and whole/liquor digestate being applied to land in Scotland
(baseline tonnages for 2017 obtained through calculations from data in ZWS (2019a))

		Forecast for year (tonnes)				
Scenario and digestate type		**2022**	**2027**	**2032**	**2037**	**Description**
1	Fibre Liquor/whole	198,762 553,129	198,762 553,129	198,762 553,129	198,762 553,129	No change: digestate production and tonnage to land remains static from 2017. (unlikely)
2	Fibre Liquor/whole	198,762 608,442	198,762 663,755	198,762 719,068	198,762 774,381	Digestate production remains the same but tonnages of whole and liquor applied to land increases by 40% over 20 years.
3	Fibre Liquor/whole	208,700 608,442	218,638 663,755	228,576 719,068	238,514 774,381	Digestate production increases by 20% and tonnages of whole and liquor applied to land increase by 40% over 20 years.
4	Fibre Liquor/whole	208,700 497,816	218,638 442,503	228,576 387,190	238,514 331,877	Digestate production increases by 20% but tonnages of whole and liquor applied to land decrease by 40% over 20 years.

However, there is much uncertainly when attempting to determine likely future tonnages of digestate in Scotland. There is strong justification for a project to determine the number of Scottish AD plants, their location, the tonnages and types of feedstock treated, the designation of outputs, (waste or non-waste), the products created (fibre, liquor or whole), the intended markets and the nature of future subsidy regimes so that the availability of suitable landbank can be determined across the regions.

Benefits and risks from the use of digestates

Given their generally high RAN content, whole and liquor digestates should be stored, handled and spread with great care in order to minimise the potential for N losses. They generally contain small amounts of other nutrients including P, K, Mg and S. Contrary to popular belief amongst many farmers, AD plant managers and AD industry representatives, whole and liquor digestates contain very little organic matter and due to the rates at which they are applied, they are not effective soil conditioners. In fact, the DC-Agri project showed slight declines in soil organic matter where some whole and liquor digestates were repeatedly applied (WRAP, 2016). Fibre digestates are completely different and behave more like strawy cattle manure. They are good fertilisers and also soil conditioners due to their higher organic matter content. Fibre digestates sometimes have a useful neutralising value and should always be tested for this property. Typical properties of whole, separated fibre and separated liquor digestates are shown in Table 2.21.

Table 2.21. Key properties of whole, separated fibre and separated liquor digestates[1,2]

			Total nutrient (kg/fresh tonne)				
	% DM	% RAN	N	P_2O_5	K_2O	MgO	SO_3
Food-based digestate, whole	4.1	79	4.8	1.1	2.4	0.2	0.7
Food-based digestate, liquor	3.8	89	4.5	1.0	2.8	0.2	1.0
Food-based digestate, fibre	27	25	8.9	10.0	3.0	2.2	4.1
Farm-based digestate, whole	5.5	78	3.6	1.7	4.4	0.6	0.8
Farm-based digestate, liquor	3.0	89	1.9	0.6	2.5	0.4	0.1
Farm-based digestate, fibre	24	25	5.6	4.7	6.0	1.8	2.1

[1]Data from SRUC (2019)
[2]Some fibre digestates may also have a liming value (testing required).

The risks associated with applying PAS 110 digestates to land have been studied extensively and published in WRAP (2017a). These risks are considered negligible when compared to the benefits to soils and crops when applying them according to best agricultural practice.

The risks of applying non PAS110 digestate that is not regulated as waste (e.g. farm-based digestate) to land in Scotland will depend on the physical and chemical properties of individual materials and on how, where and when the materials are applied. There is anecdotal evidence that non-waste digestates have been over-applied in Scotland in some cases, applied in inappropriate soil or weather conditions or applied when there is no crop demand. In such cases, the risk of N losses and pollution of water courses is high. There is the potential for other risks, such as those associated with the introduction of plant pathogens from unpasteurised digestate, or high concentrations of one or more PTEs. The type and magnitude of these risks would have to be individually quantified, depending on the nature of the individual digestates concerned and the way in which they are typically applied.

Risks to soils, animals or humans from applications of waste digestate to land are generally adequately controlled through the waste management licensing regulations (Paragraph 7 or 9 exemptions). PTE content of waste digestates is usually low enough for application at typical rates not to pose a risk to soils. The greatest risks from applying waste digestates would usually be from their high RAN content or (in some cases) high plastics content. SEPA currently control this latter risk by allowing application at rates which would apply no more plastic than typical applications of PAS 110-accredited digestates. Without the controls delivered under the Waste Management Licensing Regulations (under Paragraph 7 and 9 exemptions), application of waste digestates could pose significant risks to soils and water courses, mainly through over-application of RAN, certain PTEs in some cases and through application of plastics in other cases.

Digestates are not routinely tested for contaminants of emerging or increasing concern such as microplastics, veterinary medicines or pharmaceuticals. A recently published study on organic materials spread to land suggested that pharmaceuticals, veterinary medicines and indeed all of the most important known organic contaminants were unlikely to be present at levels generating a significant risk in digestates (WCA, 2019). For this reason, there is no reasonable case for currently demanding (in applications for Paragraph 7 and 9 exemptions) risk assessments for the presence of these hazards in each digestate being considered for land application and their likely impacts.

2.4 Distillery and other drinks wastes

This covers wastes with EWC codes 02 07 01 (wastes from washing, cleaning and mechanical reduction of raw materials), 02 07 02 (wastes from spirits distillation) and 07 02 99 (wastes not otherwise specified). Most of the wastes applied were from spirits distillation.

Tonnages applied to land and location of landbank

515,320 t and 459,546 t of all distillery and other drinks wastes (not including digestates, which are covered in Section 2.3) were applied under paragraph 7 exemptions in 2016 and 2017 respectively (Table 2.4). The wastes were produced widely across Scotland but the greatest tonnages came from Aberdeenshire, Highland and Moray, where the greatest concentrations of distilleries are located (although the location where some of the material was generated was unknown, A. Cundill, pers. comm.).

It is likely that most of these materials were applied to land which was in close proximity to (within 30 km of) the production site, because the haulage costs would be expensive in comparison to the financial value and nutrient content of the materials. However, it is not possible to tell without studying individual exemption applications.

Of all types of distillery/drinks wastes in this category (including very dilute effluents), most by-products and wastes are not applied to land. A significant proportion was discharged to sewer, river or sea in 2017, although this may have changed to some extent since the most recent data was published. Significant tonnages are used as feedstock for AD, for biomass or for animal feed, although the tonnage of draff used for animal feed has dropped greatly. The price obtained for draff as a feedstock for AD or biomass is often greater than farmers can pay for feed.

Future tonnages

It is not possible to make confident statements about the likely trends in production without contacting either the trade bodies which represent the manufacturers or the manufacturers themselves. It may be the case that production is going to drop over the next few years given the high import tariffs recently imposed by the USA. However, the African and Asian export market is expanding, with exports overall up by 4.4% in 2019 (G. Henderson, pers. comm.).

Benefits and risks associated with land application

Most of the material which is applied to land takes the form of heavy, bulky, low dry matter liquids including pot ale, distillery effluent and brewery wash water. Typical analytical data are shown in Table 2.22. The materials are applied for their plant nutrient content.

Table 2.22. Key typical properties of different types of distillery/drinks wastes[1]

			Total nutrient (kg/fresh tonne)				
Material	**DM (%)**	**% RAN**	**N**	**P_2O_5**	**K_2O**	**MgO**	**SO_3**
Distillery pot ale	5.0	4	2.5	1.8	1.1	0.2	0.02
Distillery effluent/sludge	2.5	13	1.5	1.3	0.4	0.1	0.15
Brewery wash water	1.0	13	0.3	0.2	0.1	0.02	0.1
[1]Data from SRUC, 2019.							

The main potential risk from applying drinks and distillery wastes is in increasing soil Cu and/or Zn concentrations, since some distillery by-products contain high concentrations of these elements. Whilst there is some evidence that copper (Cu) and zinc (Zn) concentrations in soil is sometimes slightly higher after distillery production residue spreading than before spreading, this is not always a bad thing (Cundill *et al.,* 2012). In areas where background Cu and Zn concentrations in soils are low, this may benefit agricultural production by contributing to a reduction in trace nutrient deficiencies. However, there are fields in which SEPA has identified very high soil Cu concentrations (mainly in fields close to distilleries). It is clearly possible for soil Cu concentrations to become very high where Cu-rich distillery wastes have been spread over a long period of time. Whilst spreading prior to the original 1994 Waste Management Licensing Regulations would not have been subject to controls, nowadays the regulatory regime should, in theory at least, prevent such high Cu concentrations developing.

2.5 Composts (other than mushroom compost)

This section covers true composts, as opposed to mushroom composts, or materials such as growing media (which in the UK are often called composts). True composts can be defined as “stable, sanitised, organic materials, which have been made commercially through mixing, self-generated heating and aeration”. There are two types made in the UK, including green composts, which are made from garden wastes only, and food/green composts, which are made from a mixture of food and garden wastes. Composts accredited through the UK Compost Certification Scheme and accredited to the BSI PAS 100 standard are not regulated as wastes so long as they are used within the terms of the relevant SEPA position statement (SEPA, 2017a).

Tonnages applied to land and location of landbank

There was 225,925 t of compost produced in Scotland in 2017 (ZWS, 2019b, Table 2.5). This excludes around 1,200 t produced on Paragraph 12 exempt sites. Production from these exempt sites has been omitted from the main total, since many of those sites are very small and many are in remote areas and so will not impact on availability of landbank in the main agricultural areas of Scotland (F. Donaldson, pers. comm.). Of the 225,925 t of compost produced (according to the ZWS report) in 2017, around 83% was PAS 100-accredited and 17% was classified as waste. Given the percentage of compost produced in-vessel, it is likely that around 43% of that produced will be food/green and 57% green, although the distinction is not very important, given that some green composts are almost as nutrient rich as “typical” food/green composts and many food/green composts are similar to green composts (Earthcare Technical assessment, based on hundreds of compost test results).

Of all the compost applied to land in 2017, it is not possible to tell from the Zero Waste Scotland (2019b) report how much of that is waste and how much is product, but of all compost produced, between 84 and 97% was applied to land. Some compost producers did not respond to the survey request (by the ZWS project team), hence the lack of a more exact figure. It is known that at least 84,407 t (38%) of the compost produced in 2017 went to agriculture and field horticulture, at least 27,289 t (12%) to landscaping and at least 76,548 t (34%) went to landfill restoration or land restoration. Some of these figures were estimates based on “grossing up” tonnages from those that did respond to the survey (ZWS, 2019b).

By 2017, there was increased use of composts in land restoration and decreased use of composts in growing media and turf manufacture (compared with 2014, ZWS, 2016, 2019b). The author’s experience in the organics recycling industry suggests that this trend may be continuing. Growing media and turf manufacturers are increasingly using constituents other than compost, whereas there has been some growth in the use of composts in land restoration as restoration of the former Scottish opencast coal sites continues apace. The high cost of PAS 100-accredited compost means that such composts are unlikely to be used in land restoration, but some off-specification material is. It is also known that some composts are being used as both daily cover and restoration materials for landfill sites. It is not yet possible to be sure, but it is likely that the use of compost in Scottish agriculture is decreasing, as many compost producers are struggling to achieve farm assurance scheme limits and new Scottish end of waste criteria for plastics content in compost. Unless significant funding is provided to help compost producers achieve cleaner composts (in terms of plastic content), it is likely that the proportion of composts going to agricultural land will decrease in future and the proportion going to land restoration will increase. There is a clear problem with the plastic content of some composts (even PAS 100-accredited composts) and a clear need to address it if composts are to have a long-term landbank in agriculture. Land restoration is only likely to provide an outlet for the next 10 years or so, since opencast mining has almost ceased in Scotland and since most closed sites are either restored, being restored at the moment or are planned to be restored.

Future tonnages

It is very difficult to predict future tonnages of compost production in Scotland. There is increasing pressure to recycle organic resources rather than dump them in landfill, but there is not yet an outright ban on landfilling organic materials. Whilst there is legislation to ensure that food-wastes are source-segregated and submitted for treatment from householders and businesses, there is still a great deal of organic material ending up in landfill. That is obvious from visits to numerous landfill sites in Scotland (Earthcare Technical). If the trend towards increasing numbers of co-mingled collections continues then the volume of compost available for land spreading is likely to increase. If the proposed ban on organic materials to landfill is brought in, particularly if it is brought in alongside a dedicated campaign to educate householders on source-segregation methods, then the tonnage of compost available for spreading is likely to increase substantially. Table 2.23 shows four possible scenarios for the tonnage of compost being produced in Scotland over 5, 10, 15 and 20 years.

Table 2.23. Possible scenarios for changes to the amount of compost[1] produced in Scotland (baseline year 2017, known tonnage was 225,925 t)

	Forecast for year (tonnes)				
Scenario	**2022**	**2027**	**2032**	**2037**	**Description**
1	225,925	225,925	225,925	225,925	Compost production remains static (unlikely)
2	230,444	234,962	239,481	243,999	Compost production increases by 8% over 20 years (possible)
3	232,703	239,481	246,258	253,036	Compost production increases by 12% over 20 years (possible)
4	237,221	248,518	259,814	271,110	Compost production increases by 20% over 20 years (possible)
[1]All composts including green and food/green, PAS100 and waste composts					

Given the pressure to reduce use of finite resources, increase the recycling of organic resources, minimise methane emissions from landfill sites, minimise organic waste collection costs and improve the health of arable soils through applications of organic matter, it seems unlikely that compost production in Scotland will fall. It is much more likely that it will increase, probably in line with at least Scenario 2 (Table 2.23). However due mainly to the difficulties in producing a PAS 100-compliant compost, the number of composting sites in Scotland has again fallen. It is thought that there are now (in 2020) as few as 20 major composting sites in Scotland and only 17 of the processes are currently listed as PAS100 certified (down from 21 in 2017), at least partly due to the difficulties in maintaining certification under the new Scottish End of Waste position for composting. The relatively small number of compost producers will almost certainly be producing similar or greater tonnages than previously, which will give rise to higher costs in transporting compost from fewer hubs out to the landbank.

Benefits and risks associated with land application

Composts are excellent fertilisers and soil conditioners. They contain significant quantities of plant nutrients, in particular P, K, Mg and S. They also contain significant quantities of useful forms of organic matter which due to the high lignin content are known to be particularly long-lasting in soils (WRAP, 2016). Green compost tends to have a slightly higher C:N ratio and slightly lower nutrient concentrations than food/green compost, but this is not always the case. Typical properties of green and food/green composts are shown in Table 2.24.

Table 2.24. Key properties of green and food/green compost[1,2]

			Total nutrient (kg/fresh tonne)					Organic matter content (kg/fresh tonne)
	DM (%)	% RAN	N	P_2O_5	K_2O	MgO	SO_3	
Green compost	60	~ 1	7.2	2.6	5.2	3.2	2.3	~ 30%
Food/green compost	60	~ 5	13.9	6.9	6.8	4.6	3.0	~ 30%

[1]Some composts, particularly food/green composts may also have a liming value of up to 10% of that of ground limestone.
[2]Data from SRUC, 2019 other than the organic matter contents, which are the average of several samples tested by Earthcare Technical.

The risks associated with applying composts to land have been studied extensively and published in WRAP (2017b). Those associated with applying PAS 100 composts to land are considered negligible when compared to the benefits to soils and crops when applying them according to best agricultural practice.

The risks of applying non PAS100 (waste) composts to land in Scotland will depend on the physical and chemical properties of the composts concerned and on how, where and when the materials are applied. PTE content of waste composts is usually low enough for application at typical rates not to pose a risk to soils. The main risks from application of waste composts would likely be from the presence of physical contaminants including plastics, metals and glass, although there is also the potential for other risks, mainly including lock-up of N from improperly stabilised compost, or the introduction of plant, human and animal pathogens from improperly sanitised compost.

SEPA currently control risks of physical contamination of soils by allowing the application of waste composts at rates which would apply no more plastic than typical applications of PAS 100-accredited composts. Without the controls delivered under the Waste Management Licensing Regulations (under Paragraph 7 and 9 exemptions), applications of waste composts could pose risks of significant contamination of soils with plastics.

Composts are not routinely tested for hazards of emerging or increasing concern such as microplastics, veterinary medicines or pharmaceuticals. There may be a case for demanding (in applications for Paragraph 7 and 9 exemptions) risk assessments for the presence of these hazards in each compost being considered for land application and the likely associated risks. There is also a need for further scientific work to evaluate the presence and risks associated with composts (particularly waste composts) made using different from different feedstocks.

2.6 Sewage sludge

This section covers all types of sewage sludge including untreated materials, conventionally and enhanced treated types.

Tonnages applied to land and location of landbank

There were 185,447 and 221,214 t of sewage sludge applied to land in Scotland in 2017/18 and 2018/19 respectively (Table 2.6). Around 53% of the 2018/19 total was applied to agricultural land and the remainder was used in land restoration. In 2018/19, around 19% of the tonnage applied was applied as enhanced-treated pellets, 24% as enhanced-treated cake, 4% as digested liquid, 6% as conventionally treated cake and 47% as untreated or non-compliant material. The above figures were obtained from Scottish water and represent only sewage sludge produced in Scotland and applied to land in Scotland.

The authors are aware of additional tonnages of sewage sludge coming into Scotland from England and Northern Ireland. For example, one land restoration company has reported that they imported around 15,000 tonnes in 2019 alone. They typically import between 10 and 30% of all sewage sludge used in restoration from outside Scotland. They also said that other restoration companies do the same or have even higher proportions of imported sewage sludge. Most of the imported and Scottish sewage sludge used in land restoration is not suitable for use in agriculture (since it has not been treated to conventional or enhanced standard). It is not known whether conventionally treated or enhanced treated sewage sludge (also termed biosolids) are also being imported for use in Scottish agriculture. It would be useful for SEPA to obtain information from sludge registers from other countries, but it may be difficult to achieve.

Future tonnages

Scottish Water's long-term strategy is to maximise the value of the sludge, by using AD or advanced AD to improve the quality of the product and at the same time derive energy from the process. Scottish Water plan to invest in new facilities over the next 20 years in order to convert more sludge to enhanced treated biosolids. Table 2.25 summarises Scottish Water's plans for sewage sludge treatment for the next 20 years. Scottish Water acknowledge that their plans will be revised where necessary where new improved technologies become available, or in the face of emerging risks or where landbank availability changes (information from Scottish Water). The plan is to produce some higher range dry solids material (through advanced anaerobic digestion) which is suitable for application to agricultural land, and some lower range dry solids material (through pyrolysis and gasification) which currently has no use and which will be disposed of to landfill.

Table 2.25. Scottish Water's forecast for production of sewage sludge over the next 20 years (baseline year 2018/19)

		Forecast for year (wet tonnes)	
		2039/40	
Sewage sludge type	**2018/19**	**Lower range total dry solids (TDS)**	**Higher range TDS**
Biosolids, enhanced treated pellets	42,021	4,996	4,996
Biosolids, enhanced treated cake	52,377	108,862	227,214
Biosolids, conventionally treated liquid	9,200	1,083	1,083
Biosolids, conventionally treated cake	12,721	4,632	4,632
Biosolids, untreated or non- compliant with standards for use in agriculture	104,895	none	none
Total tonnage to land	221,214	119,573	237,925
NB: Where the option to produce lower range TDS material is taken, sludge will be treated through alternatives to AD, e.g. pyrolysis and gasification, which produces a waste end product unsuitable for use in agriculture (hence lower total tonnage available for spreading).			

Benefits and risks associated with land application

Sewage sludges are useful fertilisers, which are applied mainly for their N and P content, although they also contain useful amounts of Mg and S (Table 2.26). They contain very little K and farmers who regularly apply biosolids to their land must apply additional bagged K to maintain soil K status. Unpublished data from SEPA audit campaigns shows that soils in fields that have received regular sewage sludge applications tend to have soil extractable P concentrations that are above optimum for the good growth of crops and extractable K concentrations that are below optimum for the good growth of crops (A. Cundill, pers. comm.).

Some types of sewage sludge also contain useful amounts of organic matter, and some (e.g. lime stabilised sludges or lime cake) have a useful neutralising or liming value. Emerging technologies are likely to produce biosolids products with different chemical composition, therefore it will be important to test them sufficiently to gain robust information on their nutrient value and variability.

Table 2.26. Key typical properties of different types of sewage sludge[1,2,3]

			Total nutrient (kg/fresh tonne)				
Sewage sludge type	**DM (%)**	**% RAN**	**N**	**P_2O_5**	**K_2O**	**MgO**	**SO_3**
Digested cake	25	15	11.0	11.0	0.6	1.6	8.2
Lime cake	25	11	8.5	7.0	0.8	2.4	7.4
Digested liquid	1.7	75	0.7	1.0	0.1	N/A	N/A
Thermally dried pellets	95	5	40	55.0	2.0	6.0	23.0

[1]Some sewage sludge (lime-stabilised, “often called lime cake”), also have a liming value of between 4 and 18% of that of ground limestone.
[2]Digested cake and lime cake can have useful organic matter contents (around 15 to 20% of the fresh weight).
[3]Data from SRUC, 2019 other than for the digested liquid, which is from Scottish Water.

The risks associated with applying sewage sludge to land have been extensively studied in recent years. There is no evidence of adverse impacts upon soil or the wider environment resulting from sewage sludge applications. Those associated with potentially toxic elements are managed through the Sludge (Use in Agriculture) Regulations 1989 and a recent report by SEPA has shown that the risks from PTEs to soil are being effectively managed (WCA, 2019). However, very little is known about the impact on soil quality and the wider environment of the lesser known PTEs such as platinum and palladium, but they have gained importance in recent years and have been found in sewage sludge (Cundill *et al*., 2012).

WCA have conducted risk assessments associated with the organic contaminants present in a range of organic materials including sewage sludge (WCA Environment, 2014 and 2019). They concluded that (with the measured concentrations of contaminants in the materials studied, which included sewage sludge) if the materials were spread to land, the risks to human health and the environment were likely to be low under current application practices (and following good practice) from the prioritised chemicals for which hazard data are available. However, they also said that it was not currently possible to establish maximum safe spread rates for any of the materials examined due to residual uncertainties in factors such as field degradation rates and predicted no effect concentrations (PNECs). Further work is required in this respect, and possibly with regard to microplastics and synthetic fibres which are being reported as a potential future issue (Corradini *et al.,* 2019).

It is likely that regulation of sewage sludge in Scotland will change in future. The principal reasons for change are:

- the current regulatory regime is complex

- there have been changes to the supply chain
- there have been changes to treatment processes, with a greater focus on the energy value of sludge
- new hazards are emerging
- there have been complaints, pollution incidents and poor management practices involving septic tank sludge

In short, there are risks associated with continuing under the current regime, and a lack of opportunity to safely take advantage of new opportunities for dealing with sludge. In 2016, SEPA and Scottish Government published a review of the storage and spreading of sewage sludge on land in Scotland (Scottish Government, 2016b). Amongst other things, it concluded that the way in which sewage sludge is currently regulated in Scotland (through the Sludge (Use in Agriculture) Regulations (SUiAR) and the Waste Management Licensing Regulations (WMLR)) should be revised and updated. The 2017 SEPA and Scottish Government Consultation on Proposals for an Integrated Authorisation Framework included broad proposals to update the regulations on sewage sludge so that future regulatory control is in-line with the Sludge Review recommendations (SEPA and Scottish Government, 2017).

The location of all sewage works which produce outputs which are applied to land are known and their location mapped (Section 3.4.1). The land to which the sewage sludge is applied typically lies within a 30 km radius of the outlet, although this distance can be greater where agricultural markets are scarce (e.g. around Glasgow). In fact most sludge from the Glasgow area is currently burnt as waste-derived fuel in the cement manufacturing industry, but the long term strategy for this area is to move to AD or advanced AD and a land-based outlet for the resulting biosolids. The digested liquid tends to be transported for shorter distances (less than 12 km) due to its lower financial value per unit weight/volume. The thermally dried pellets may be transported further due to their higher value per unit weight.

2.7 Wastes from pulp, paper and card production and processing

This covers wastes with EWC codes under group “03 03” but only three types have been applied recently in Scotland including: 03 03 01 (Waste bark and wood), 03 03 11 (Sludges from on-site effluent treatment plants (virgin pulp, no inks)) and 03 03 99 (De-inked sludge from paper recycling and ink-free paper crumble from virgin pulp). These three types can be applied under a Paragraph 7 exemption only. Material covered by codes 03 03 11 and 03 03 99 is usually termed paper crumble, which is the residue from the preparation of recycled paper prior to its re-use in the paper production process, or from the processing of virgin fibre from a variety of fibre sources, such as wood or cotton. It contains short cellulose fibres which are not suitable for use in paper production, printing inks and mineral components such as kaolin, talc and calcium carbonate.

Tonnages applied to land and location of landbank

There are no records of other pulp, paper or card wastes other than those listed above having been applied under Paragraph 9 exemptions in 2016 or 2017. In total, 29,746 t were spread in 2016 under Paragraph 7 exemptions and 24,109 t were spread in 2017 (Table 2.7). All the wastes were produced in Aberdeen and Fife, which is where the remaining paper mills are based (A. Cundill, pers. comm.). However, the production location of significant tonnages was not recorded.

Most of these materials were applied to land which was in close proximity to (within 30 km of) the production site, because the haulage costs would be expensive in comparison to the financial value and nutrient content of the materials (A. Cundill, pers. comm.). However, it is not possible to tell exactly where these were spread without studying individual exemption applications.

Future tonnages

It is not possible to make confident statements about the likely trends in production without contacting the manufacturers themselves. The number of pulp and paper mills in Scotland has decreased over the years, and it is unlikely that the tonnages produced are going to increase significantly.

Benefits and risks associated with land application

It is thought that most pulp, paper and card wastes are applied to land for agricultural benefit because they are too wet to burn effectively without drying. Most of the material which is applied to land takes the form of heavy, bulky, stackable solids. They are typically applied as soil conditioners for their organic matter content and liming value, but some types (particularly the biologically treated types) contain useful amounts of plant nutrients including Mg and/or S. The materials often have a high C:N ratio and are applied to lock up N in the autumn in fields with a high residual N value. Alternatively, it is common practice to mix paper crumble with dung, turn it a few times and apply the mixture a few months later. Typical analytical data are shown in Table 2.27.

The main potential risk from applying paper crumble to land is from its heavy metal content. Biologically-treated paper crumble (sludge) typically has higher nutrient and heavy metal contents than chemically/physically-treated paper crumble (Gibbs *et al.,* 2005); these differences are a result of using biologically active materials, such as sewage sludge, to drive the biological treatment process. Of the 25 fields treated with paper crumble and sampled as part of the SEPA soil compliance monitoring campaign, none have been found to contain PTE concentrations near to or in excess of the 1989 Sludge (Use in Agriculture) Regulations limits. However, this was at least partly due to the very low PTE content in the receiving soil prior to application of the waste (C. Erber, pers. comm.).

Fungicides and bactericides are also likely to be present in paper wastes, but there has been little published work to evaluate the concentrations of products of concern, or their likely impact on soils or the wider environment. Studies conducted by WCA on behalf of SEPA also concluded that dioxins, dioxin-like poly-chlorinated biphenyls (PCBs) and polybrominated diphenyl ethers (PBDEs) were also identified as potential contaminants of concern in paper wastes (WCA, 2014; 2019). However, further study is required to determine the nature of hazard and risk posed by these contaminants when paper wastes are spread to land.

Table 2.27. Key typical properties of the two main types of paper wastes used in Scotland[1,2,3]

			Total nutrient (kg/fresh tonne)				
Material	**DM (%)**	**% RAN**	**N**	**P_2O_5**	**K_2O**	**MgO**	**SO_3**
Paper crumble (chemically/physically treated)	40	5	2.0	0.4	0.3	0.2	0.02
Paper crumble (biologically treated)	30	11	7.5	3.8	0.4	0.3	0.02

[1]Data from SRUC, 2019. [2]Most types of paper crumble also have a neutralising value which is typically between about 1 to 16 % of that of ground limestone (Rollet *et al.,* 2015). [3]Paper crumbles are also useful soil conditioners which typically contain between 9 and 28% of organic matter in the fresh material (Rollet *et al.,* 2015).

2.8 Non-meat food wastes

Non-meat food wastes cover a range of different waste types with EWC codes under groups “02 03, 02 05 and 02 06” but only those permitted for application under Paragraph 7 exemptions are covered here (none are permitted for application under Paragraph 9 exemptions). Broadly, the wastes covered include: 02 03 01 (sludges from washing, cleaning, peeling centrifugation and separation, including mushroom composts); 02 03 02 (wastes from preserving agents); 02 03 04 (materials unsuitable for consumption or processing); 02 03 05 (sludges from on-site effluent treatment; 02 05 01 (dairy wastes unsuitable for consumption and processing) and 02 06 03 (bakery and confectionary wastes: sludges from on-site effluent treatment).

Tonnages applied to land and location of landbank

In total, 49,866 t of these materials were spread in 2016 and 23,264 t were spread in 2017 (Table 2.8). Material has originated mainly in Aberdeenshire, East Lothian and the Borders, but some has originated from unrecorded locations. It is likely that most of these materials were applied to land which was in close proximity to (within 30 km of) the production site, because the haulage costs would be expensive in comparison to the financial value and nutrient content of the materials. However, it is not possible to tell without studying individual exemption applications and benefit statements.

Future tonnages

It is not possible to make confident statements about the likely trends in production of these types of wastes without knowing more about the materials in question and their production methods. However, the amounts applied are fairly small and the tonnages insignificant in comparison to materials such as sewage sludge, digestates, distillery wastes and composts. There is no information which suggests that a large increase in future tonnages is likely, therefore perhaps the best plan is to assume that tonnages are likely to remain similar in future years.

Benefits and risks associated with land application

Many of the materials in this category are liquids which are applied to land primarily for their nutrient content or the water that they contain (given that some materials contain mainly water). Individual materials are likely to vary considerably from the so called “typical” values published in SRUC (2013). Some of these liquids will have high RAN content and many are likely to have high biological or chemical oxygen demands. Their analysis should therefore be interpreted by sufficiently competent persons (who should be preparing the Certificates of Agricultural Benefit required under Paragraph 7, 8 and 9(1) exemptions). The person preparing the benefit statement should state the way in which the material in question should be applied and the precautions which should be taken to minimise nutrient losses. Other materials in this group, principally mushroom compost, are solids which are both fertilisers and soil conditioners as well as liming agents. Representative analytical data are shown in Table 2.28.

There are no particular risks to either soil quality or human health from applying materials with this series of waste codes to land. However, due to variability between different types of material, the risks from spreading it should be assessed on a case by case basis. Parameters which could have undesirable values which could result in risks which have to be managed during storage and application to land include biological and chemical oxygen demand, neutralising value, conductivity and RAN content. Analysis of individual materials as required for preparation for certificates of agricultural benefit will provide the necessary information to complete risk assessments and plans for safe, beneficial application.

Table 2.28. Typical key properties of different types of non-meat food wastes[1,2]

			Total nutrient (kg/fresh tonne)				
Material	**DM (%)**	**% RAN**	**N**	**P_2O_5**	**K_2O**	**MgO**	**SO_3**
Dairy wastes	4	N/A	1.0	0.8	2.9	N/A	N/A
General food wastes	5	N/A	7.5	3.8	0.4	N/A	N/A
Spent mushroom compost	35	N/A	1.6	0.7	0.2	N/A	N/A

[1]True values from materials of this type are likely to vary widely from the so-called “typical” values presented here which are from SRUC (2013).
[2]Mushroom composts generally have a neutralising value which is typically between about 20 to 60 % of that of ground limestone (results from testing Earthcare Technical samples).They are also useful soil conditioners which typically contain similar amounts of organic matter to strawy cattle manures (between 10 and 20% in the fresh material).

2.9 Meat, fish and animal origin food wastes

This section covers waste with a single EWC code: 02 02 03 (wastes from the preparation and processing of meat, fish and other foods of animal origin - Materials unsuitable for consumption or processing consisting of blood and gut contents from abattoirs, poultry preparation plants or fish preparation plants; wash waters and sludges from abattoirs, poultry preparation plants or fish preparation plants; and shells from shellfish processing). They are permitted for land application under Paragraph 7 exemptions only.

Tonnages applied to land and location of landbank

In total, 28,605 t of these materials were spread in 2016 and 18,254 t were spread in 2017 (Table 2.9). Material has originated in a few local authority areas, mainly Aberdeenshire, North Ayrshire, Perth and Kinross, Scottish borders, but some has originated from unrecorded locations. It is likely that most of these materials were applied to land which was in close proximity to (within 30 km of) the production site, because the haulage costs would be expensive in comparison to the financial value and nutrient content of the materials. However, it is not possible to tell without studying individual exemption applications and benefit statements.

Future tonnages

It is not possible to make confident statements about the likely trends in production of these types of wastes without knowing more about the materials in question and their production methods. However, the amounts applied are fairly small and the tonnages insignificant in comparison to materials such as sewage sludge, digestates, distillery wastes and composts. There is no information which suggests that a large increase in future tonnages is likely, therefore perhaps the best plan is to assume that tonnages are likely to remain similar in future years. These materials may be diverted from land spreading to AD plants in future where the distances involved mean that haulage costs are affordable.

Benefits and risks associated with land application

Many of the materials in this category are liquids which are applied to land primarily for their nutrient content. Some of these liquids are likely to have high RAN content and many are likely to have high biological or chemical oxygen demands. Their analysis should therefore be interpreted by experts in order to determine the most appropriate application methods and they should be applied with care. Other materials in this group, principally gut contents from abattoirs, are solids which are both fertilisers and soil conditioners. There is no published data showing the wide range of different chemical and physical properties from wastes of this type.

Where waste of code 02 02 03 is applied to land, evidence must be provided to the person applying the waste (and the person to whose land the waste is applied) that it has been treated in accordance with the Animal By-Products (Scotland) Regulations 2003. Given that this must happen, there are no particular risks to either soil quality or human health from applying materials of this type to land. Parameters which could have undesirable values which could result in risks which have to be managed during storage and application to land include biological and chemical oxygen demand, neutralising value, conductivity, and RAN content. Analysis of individual materials as required for preparation for certificates of agricultural benefit will provide the necessary information to complete risk assessments and plans for safe, beneficial application.

2.10 Water treatment sludge (or clean water sludge)

This section covers a single waste code (19 09 02) which covers wastes from the preparation of water intended for human consumption or water for industrial use – (sludges from water clarification).

Tonnages applied to land and location of landbank

Water treatment sludges can be applied under Paragraph 7 and 9 exemptions, but in practice very little of this material is currently applied to agricultural land. In 2017/18, 32,713 t was applied (with only 1,895 t or 5.7% of the total to agricultural land, Table 2.10). In 2018/19, 29,173 t was applied (with only 1,291 t or 4.4% of the total to agricultural land).

The water treatment sludge applied to land in Scotland was produced in 16 local authorities across Scotland. It is likely that the small amount of material spread under Paragraph 7 exemptions was applied to land which was in close proximity to (within 30 km of) the production site. However, the great majority of that spread under Paragraph 9(1) exemptions will have gone to the major Scottish restoration sites in Ayrshire, Fife and North/South Lanarkshire (C. Erber, pers. comm.).

Future tonnages

Discussions with Scottish Water have suggested that although the tonnages of this material produced annually are unlikely to change, the intention is to begin an investigation into the potential for increased use of the material in Agriculture, since the current land restoration landbank is likely to dwindle to next to nothing over the next 15 to 20 years.

Benefits and risks associated with land application

The materials in this category are generally fairly heavy and contain sand, silt and clay particles as well as variable but useful amounts of organic material and fertiliser nutrients (Table 2.29). Some types have a small liming value *(Rollet et al.,* 2015), although this is usually thought to be negligible (A. Cundill, pers. comm.).

Table 2.29. Typical key properties of water treatment sludge[1]

		Total nutrient (kg/fresh tonne)				
DM (%)	**RAN (%)**	**N**	**P_2O_5**	**K_2O**	**MgO**	**SO_3**
25	4	2.4	3.4	0.4	0.8	5.5
[1]Values are from SRUC (2013).						

There are some concerns over the application of clean water sludge to agricultural land, particularly in relation to their often-high Al concentrations and their ability to lock up phosphates. Further study will be required to determine the nature of these risks and measures required to alleviate them before the material is likely to be used widely in agriculture.

2.11 Plant tissue wastes

This section covers a single waste type: 02 01 03 (Plant tissue wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing), which is permitted for land application under Paragraph 7 exemptions only.

Tonnages applied to land and location of landbank

In total, 9,791 t of this material were spread in 2016 and 12,140 t were spread in 2017 (Table 2.11). Material has originated in a few local authority areas, mainly in the City of Edinburgh and Dumfries and Galloway, with smaller amounts coming from Aberdeenshire, East Lothian, Highland, Midlothian and North Lanarkshire, but a significant proportion of the tonnage applied has originated from unrecorded locations. It is likely that most of these materials were applied to land which was in close proximity to (within 30 km of) the production site, because the haulage costs would be expensive in comparison to the financial value and nutrient content of the materials. However, it is not possible to tell without studying individual exemption applications.

Future tonnages

It is not possible to make confident statements about the likely trends in production of these types of wastes without knowing more about the materials in question and their production methods. However, the amounts applied are fairly small and the tonnages insignificant in comparison to materials such as sewage sludge, digestates, distillery wastes and composts. There is no information which suggests that a large increase in future tonnages is likely, therefore perhaps the best plan is to assume that tonnages are likely to remain similar in future years.

Benefits and risks associated with land application

The materials in this category are generally solids such as cereal dust, husks, plant tops, shaws, offcuts and waste from vegetable processing factories which are applied to land for their nutrient and organic matter content. There is no published data on the physical and chemical properties of these materials. However, the author's experience suggests that these are likely to be extremely variable.

There are no particular risks to either soil quality or human health from applying materials with this waste code to land. Parameters which could have undesirable values which could result in risks which have to be managed during storage and application to land include N content in some vegetable wastes such as brassicas. Analysis of individual materials as required for preparation for certificates of agricultural benefit will provide the necessary information to complete risk assessments and plans for safe, beneficial application.

2.12 Waste ash

This section covers three waste codes within the group "10 01" (Wastes from power stations and other combustion plants (except wastes from waste management facilities, off site waste water treatment plants and the preparation of water intended for human consumption and water for industrial use). These include 10 01 01 (bottom ash from the combustion of biomass or pig and poultry carcasses) which can be spread under Paragraphs 7 and 50. (Paragraph 50 covers only ash from the combustion of pig or poultry carcases). Also included is 10 01 02 (pulverised fuel ash), which can be spread under a Paragraph 9 only and 10 01 03 (Fly ash from peat and untreated wood) which can be spread under Paragraphs 7 and 9 only.

Tonnages applied to land and location of landbank

A total of 5,144 t of bottom ash was spread under Paragraphs 7 and 50 in 2017; a total of 750 t of pulverised fuel ash was spread under Paragraph 9 in 2017 and a total of 4,343 t of fly ash was spread under Paragraph 7 exemptions only in 2017 (Table 2.12). The total amount of waste ash spread to land in 2016 was 7,087 t and in 2017 was 10,237 t.

Most ash wastes produced in the UK are used in civil engineering applications such as construction of roads and stable platforms for buildings, rather than in land application. Most of the ash waste applied to land in both 2016 and 2017 was from unrecorded locations, although some came from Highland Region. Most of this material was applied to land which was in close proximity to (within 30 km of) the production site (C.Erber, pers. comm.).

Future tonnages

It is not possible to make confident statements about the likely trends in production of waste ash without knowing more about the materials in question and their production methods. However, the amounts applied are fairly small and the tonnages insignificant in comparison to materials such as sewage sludge, digestates, distillery wastes and composts. Given the increase in biomass boilers, it is likely that tonnages of waste ash will increase in future, but a more detailed study of the issue is needed in order to make firm predictions on trends.

Benefits and risks associated with land application

The materials in this category are generally fairly light, powdery materials which are not suitable for stacking outdoors due to their propensity to blow away in windy conditions and become sludges in wet conditions. Both the beneficial and potentially harmful properties of materials in this category are likely to vary widely depending on what they are produced from and how they are produced (Rollet *et al.,* 2015). There is little published data on the physical and chemical properties of ash wastes. Some examples are shown in Table 2.30, but testing of individual samples from different sources and processes will show that the properties may vary quite a bit from the values shown below. In general, waste ash is applied for its liming value and sometimes also for its major nutrient content (particularly P and K). Its high P content can sometimes limit the application rate.

Table 2.30. Typical key properties of different types of ash wastes[1,2]

		Total nutrient (kg/fresh tonne)				
Ash from burning	**DM (%)**	**N**	**P_2O_5**	**K_2O**	**MgO**	**SO_3**
Distillery residues	36	1.6	2.1	6.5	4.2	3.9
Softwood logs	100	1.8	32.1	111.0	55.4	39.6
Hardwood logs	100	1.1	16.6	78.2	34.2	16.5
Coal fly ash	N/A	0.0	0.09 - 18.3	1.8 – 42.0	0.7 – 129.0	2.5 - 37.5
Peat/wood fly ash	N/A	0.0	22.9	24.0	N/A	N/A

[1]Values for ash produced from distillery residues, softwood and hardwood logs are from single samples of materials tested as part of Earthcare Technical's routine work (data unpublished). Typical total nutrients of coal fly ash and peat/wood fly ash are from Rollet *et al.* (2015).
[2]Many ash wastes have a high neutralising value, therefore this property should always be tested when ash wastes are being considered for application to land.

Since wood ash contains oxides and hydroxides of calcium (Ca), magnesium (Mg), potassium (K), and, to a lesser extent, sodium (Na), it can act in a similar way to burnt or hydrated lime. Many ash wastes therefore have high neutralising values (up to 90% of that of ground limestone) and the neutralising value should always be tested when considering applying them to land (information based on testing of client's samples conducted by Earthcare Technical).

PTE content and concentrations of organic compounds such as dioxins and furans can also be high in some ash wastes, depending on the material burnt and the process by which it has been burnt and the location where the feedstock was grown.

There are risks associated with the application of some types of waste ash to land. The main potential risks are from unacceptably high concentrations of one or more PTEs and organic chemicals such as dioxins and furans. The fine particles of ash wastes can make them difficult to handle in their dry state and application can be difficult for that reason. Inhalation by humans and other animals can be a problem unless the materials are handled with care. Thorough analysis of individual materials, including testing of a wide range of parameters additional to the usual ones (e.g. PTEs such as As, Al and B and organic contaminants such as dioxins and furans) will be required for preparation for risk assessments required prior to registering exemptions. Only a suitably extensive suite of test parameters will provide the necessary information to complete risk assessments and plans for safe, beneficial application.

2.13 Wastes from wood processing

This section covers two waste codes: 03 01 01 (Wastes from wood processing and the production of panels and furniture - Waste bark and wood) and 03 01 05 (Wastes from wood processing and the production of panels and furniture - sawdust shavings, cuttings, wood, particle board). Both waste types are permitted for land application under Paragraph 7 exemptions only. No waste of code 03 01 01 was applied to land in 2016 or 2017 in Scotland: most or all of it went to composting facilities (C. Erber, pers. comm.).

Tonnages applied to land and location of landbank

The total amount of wood wastes of code 03 01 05 spread to land in 2016 was 1,458 t and in 2017 was 1,906 t (Table 2.13). Material has originated only in Highland Region in 2016 and 2017 and none came from unrecorded locations. All of this material was applied to a single farm in Highland Region (A. Cundill, pers. comm.).

Future tonnages

It is not possible to make confident statements about the likely trends in production of wood processing wastes, although it seems possible that the tonnages of virgin wood wastes may decrease in future due to the subsidy available for biomass burning. The amounts applied are fairly small and the tonnages insignificant in comparison to materials such as sewage sludge, digestates, distillery wastes and composts. The best plan is probably to assume that tonnages are likely to remain similar in future years.

Benefits and risks associated with land application

The materials in this category are fairly dry, stackable solids, which tend to be applied primarily for their organic matter content. Although there is little published data on the physical and chemical properties of wastes from wood processing, Earthcare Technical has made a study of them and has some recent data to show typical properties (Table 2.31).

Table 2.31. Typical key properties of different types of wood wastes[1]

				Total nutrient (kg/fresh tonne)				
Material	**DM (%)**	**Organic matter content (%)**	**C:N ratio**	**N**	**P_2O_5**	**K_2O**	**MgO**	**SO_3**
Softwood sawdust	50	50	486:1	0.5	0.1	0.3	0.1	0.2
Softwood chip	49	49	605:1	0.4	0.1	0.3	0.2	0.4
Hardwood chip	67	64	91:1	3.6	0.9	2.2	0.9	1.0
Mixed timber chip	42	40	123:1	1.7	0.6	1.3	0.6	0.5
[1]Values from materials tested as part of a Knowledge Transfer Innovation Fund-funded project looking at the potential for wood chip bedding for livestock in the west of Scotland (data unpublished as yet).								

The organic matter contents are generally high, and the nutrient content generally low. A key feature is the high C:N ratios, which mean that the materials will lock up N when they are applied to soil. This can be a useful property if the intention is to immobilise N where high RAN materials have been applied or where residual N concentrations are undesirably high, for example following a brassica crop. However, wood-based materials should be applied with care in order to ensure that N lock up does not prevent the growth of crops, trees or amenity vegetation. There is considerable interest currently developing in agriculture for the potential for wood chip composts and wood chip bedding manures as potential sources of organic matter for soils which are lacking in organic matter. There is almost no published data on the properties of such materials, although several projects are in progress to address the lack of information.

The risks of applying wastes from wood processing to land will depend on the physical and chemical properties of the materials and on the application rates and situations in which they are applied. The PTE content of wood wastes is thought to be generally low enough for application at typical rates not to pose a risk to soils, although assessment of further sets of test data or analysis of more samples would be required in order to be sure of this. The main risks from application of wood wastes composts would likely be from N immobilisation in receiving soils, but there is also the potential for presence of physical contaminants including plastics, metals and glass. Organic contaminants were also suspected to have been a problem with one waste of this type (A. Cundill, pers. comm.). Without the controls delivered under the Waste Management Licensing Regulations (under Paragraph 7 exemptions), applications of wood processing wastes composts could pose risks of contamination of soils with organic and/or physical contaminants.

There may be a case for demanding (in applications for Paragraph 7 exemptions) risk assessments for the presence of these and other potential hazards in each wood processing waste being considered for land application and the likely associated risks. There is also a need for further scientific work to evaluate the risks associated with using animal manures made with wood wastes, since these are likely to be produced in increasing quantities in agriculture in future, as the price of straw continues to increase.

2.14 Wastes from chemical production including gypsum from various sources

This covers sludges from on-site effluent treatment (not containing dangerous substances) under EWC code 07 07 12. The waste in this case is known to be gypsum; almost certainly a waste from the production of vitamin C (C. Erber, pers. comm.) This section also covers gypsum in the forms of: wastes from the manufacture, formulation, supply and use (MFSU) of acids (06 01 99); wastes from power stations and other combustion plants (except wastes from waste management facilities, off site waste water treatment plants and the preparation of water intended for human consumption and water for industrial use) (10 01 99) and wastes from manufacture of cement, lime and plaster and articles and products made from them (10 13 04).

Tonnages applied to land and location of landbank

All of the waste codes under consideration in this section can theoretically be applied in Scotland under Paragraph 7 exemptions and those coded 07 07 12 can also be applied under Paragraph 9 exemptions. However, only wastes coded 07 07 12 were applied to land.

In 2016, 970 t of material coded 07 07 12 were applied under paragraph 7 exemptions but none were registered in 2017. In 2016, 943 t were applied under paragraph 9 exemptions and 762 t in 2017 (Table 2.14). The production location of the above material was either unknown or in Ayrshire or the Borders. If the materials had a high bulk density then it is more than likely that the applications were made to land which was in close proximity to the production site, because the haulage costs would be expensive. However, it is not possible to tell without studying individual exemption applications and benefit statements.

No wastes from chemical production with other waste codes permitted under Paragraph 7 exemptions were applied to land in 2016 or 2017. Much of the waste gypsum produced in Scotland is thought now to be used mainly in the manufacture of construction materials.

Future tonnages

It is not possible to make confident statements about the likely trends in production without knowing more about the materials in question and their production methods. It is thought that much of the tonnage applied was from a single factory in Ayrshire. However, the producer in this case has agreed with SEPA that it will not be regulated under waste controls. The amounts of this material applied to land will be small and the tonnages insignificant in comparison to materials such as sewage sludge, digestates, distillery wastes and composts. There is no information which suggests that a large increase in future tonnages is likely. There is no information about the properties of the materials in question and no information about potential agricultural or ecological benefit, though again this could be obtained from studying individual exemption applications and benefit statements where required.

Benefits and risks associated with land application

Gypsum (both waste and non-waste) was formerly applied to agricultural and land restoration soils at around 2 to 6 t/ha with the aim of helping to improve the structure of heavy soils (by flocculating clay particles within them). However, there is arguably no scientific justification for applying gypsum for this purpose other than in sodic soils (which are not prevalent in Scotland). For that reason, the material is rarely applied now other than as a calcium or sulphur fertiliser in agriculture, in which it is typically applied at much lower rates (i.e. a few kg/ha rather than a few t/ha). Given that the agriculturally beneficial spread rate is low, it is often not economically viable to apply the material under Paragraph 7 exemptions.

There are no specific known risks to either soil quality or human health of applying materials with this waste code to land at the rates which would provide agricultural benefit. Were gypsum to be applied at several tonnes/ha, as it formerly was in an attempt to flocculate clay soils, then it may cause over-accumulation of S and soil acidification. Each candidate material should be studied individually on receipt of applications for paragraph 7 and 9 exemptions in relation to the presence of known contaminants in each and presence of hazards of emerging or increasing concern.

3 Mapping; spatial assessment of benefits and controls

The purpose of Section 3 is to provide a geographical information systems (GIS) data set that helps to determine the land area in Scotland which is suitable for spreading (taking into consideration the constraints outlined in Section 1), the location of production of the materials under consideration and the tonnages being produced across Scotland (based on information presented in Section 2).

The GIS dataset is as comprehensive as possible, given the data that we have access to at time of writing, providing a tool for planning purposes. The limitations of the GIS dataset as it stands are discussed in the relevant sections. It is not possible (within the limitations set in this project) to determine exactly where, across the whole of Scotland, there will be shortages of landbank. An example of how this can be done in future has been given, by providing a detailed study of a single inter-catchment (where an inter-catchment is defined as "an area of a river catchment which sits between two named tributaries") (Appendix B).

The GIS datasets which have been created as part of this project are:

- Land where there is an absolute restriction on the spreading of organic materials (Table 3.1).
- Slope constraints (Table 3.2)
- Plant available nutrient dynamics at a national scale: crop fertiliser demand (Table 3.3)
- Scottish net annual crop demand for N, P and potassium (K) (Table 3.4)
- Geospatial spreading risk (Table 3.5)
- Designated sites (Table 3.6)
- Amounts of NPK produced annually across Scotland from livestock sources (Table 3.7)
- Scottish Water sewage sludge: current (2018) and projected (2040) production (NPK) and locations for figures (Table 3.8).
- Point sources of organic nutrients that can potentially be applied to land - AD and compost facilities (Table 3.9)
- Point sources of organic nutrients that can potentially be applied to land - distillery and brewery locations (Table 3.10)
- Economic modelling focusing of livestock markets and impact on livestock manure and slurry generation (Table 3.11)

The datasets have been described in summary in Tables 3.1 to 3.11 and in more detail in Sections 3.1 to 3.8. Examples of some of the maps that can be created through using the data set are provided in Appendix A. These maps are for illustration purposes only. The GIS dataset will only function properly when used as a standalone tool. Details of the methods used to construct the GIS datasets are provided below.

It is recognised that this spatial assessment of benefits and controls is primarily focused on agriculture as the primary outlet due to the lack of relevant spatial information on forestry, amenity and land restoration.

Table 3.1. Land where there is an absolute restriction on the spreading of organic materials.
Land that falls within the legally required buffer strips around features such as water bodies have been included in the no-spread category.

Data Set name and scale at which constraint has been mapped	Data source	Notes on data and how it can be used	Limitations to data
Name: 01_2019_National_No_Spread Scale: 1:1250,1:2500 and 1:10000	The data is an amalgamation of datasets. 1. Obtained from Ordnance Survey Vector Map District. www.ordnancesurvey.co.uk/docs/product-guides/os-vectormap-district-product-guide.pdf 2. Urban /rural settlements are derived from National Records of Scotland (updated 2018 from records 2016). www.nrscotland.gov.uk/statistics-and-data/geography/our-products/settlements-and-localities-dataset 3. Native Woodlands Survey Scotlandhttps://data.gov.uk/dataset/da3f8548-a130-4a0d-8ddd-45019adcf1f3/native-woodland-survey-of-scotland-nwss 4. All forest and woodland area over 0.5 hectare with a minimum of 20% canopy cover (or the potential to achieve it) and a minimum width of 20 metres, including areas of new planting, clearfell, windblow and restocked areas. http://data-forestry.opendata.arcgis.com/datasets/b71da2b45dde4d0595b6270a87f67ea9_0	Contains areas in a single layer where legal restraints on the land spreading of organics exist due to the presence of surface and tidal waters; road and rail zones; urban and rural settlement, and woodland cover. To calculate the legally spreadable land base over a user defined area. The identity of the feature that has been classed as no-spread has been retained.	Licence: www.nationalarchives.gov.uk/doc/open-government-licence/version/3/ Interpretation: The data set shows land, including legally required buffers to which land spreading of organics is not allowed. The data set does not identify "agricultural land" and land management usages such as rural parkland and golf courses. These would not typically be used for land spreading but are not distinguished from agricultural land as there is no legal reason for their exclusion. Land spreading controls arising from the presence of point sources used for abstraction of drinking water or the presence of springs and wells have not been included.

Table 3.2. Slope constraints
Covers areas where local land form should be a consideration when determining the risk to water quality from the spreading of organic materials

Data Set name and scale at which constraint has been mapped	Data source	Notes on data and how it can be used	Limitations to data
Name: 02_Scotland_Slopes_excess_15 Scale: National 50 m resolution 1:5000	OS open data www.ordnancesurvey.co.uk/opendatadownload/products.html	Slopes in excess of 15 degrees. Vector data extrapolated from an amalgamation of 50 m resolution digital terrain models. Data can be used to consider the risk of surface runoff from material applied to sloping land.	Licence: www.ordnancesurvey.co.uk/opendatadownload/products.html The 50 m resolution of both data sets will limit interpretation at the smaller scales.
Name: 03_Scotland_Slopes_excess_25 Scale: National 50 m resolution 1:5000	OS open data www.ordnancesurvey.co.uk/opendatadownload/products.html	Slopes in excess of 25 degrees. Vector data extrapolated from an amalgamation of 50 m resolution digital terrain models. Data can be used to consider the risk of surface runoff from material applied to sloping land.	

Table 3.3. Plant available nutrient dynamics at a national scale: crop fertiliser demand
Modelling result showing plant available nutrient dynamics at a national scale.

Data Set name and scale at which constraint has been mapped	Data source	Notes on data and how it can be used	Limitations to data
Name: 04_2015_Fertiliser_crop_demand_Nitrogen Scale: 2 km; Units: kg/ha	Model result developed by Leinonen, *et al*., (2019). The model used data inputs based on 2015 census data.	2015 data derived from Nutrient dynamics model designed by Leinonen, et al., (2019) The data set(s) provide an estimate of the annual "actual" crop nutrient demand for NPK based on actual yields. Data can be used to determine crop nutrient (NPK) demand per 2 km grid square.	Generalised data from model is restricted by 2 km resolution; averaging out of fertiliser rates available for specific crops and cultivation periods. Agricultural Census grid square data is constructed as a scaled estimate from data collected at the Agricultural Parish level geography. http://agcensus.edina.ac.uk/agcen2.pdf Data is based 2015 agricultural information and cannot be updated without baseline modelling
Name: 05_2015_Fertiliser_crop_demand_Phosphorus/Phosphate (both elemental P and P_2O_5 are provided) Scale: 2 km; Units: kg/ha			
Name: 06_2015_Fertiliser_crop_demand_Phosphorus/Potash (both elemental K and K_2O are provided) Scale: 2 km; Units: kg/ha			

Table 3.4. Scottish net annual crop demand for N, P and K
Modelling results showing net annual N,P and K crop demand for Scotland.

Data Set name and scale at which constraint has been mapped	Data source	Notes on data and how it can be used	Limitations to data
Name: 10_2015_Net_demand_surplus_Nitrogen Scale: 2 km Units: kg/ha	Model Result developed by Leinonen, *et al*., (2019) Agcensus 2015 http://agcensus.edina.ac.uk/	Derived data set by applying nutrient derived by using NPK arising from livestock nutrients to meet annual crop demand. The derived data set(s) provide an estimate of the "actual" net fertiliser demand once nutrients from livestock sources are accounted for. It assumes that nutrients from livestock source are applied in the same area and year that they arise. Negative numbers indicate a remaining demand for fertiliser. Positive results indicate a net surplus due to high levels of nutrients arising from livestock sources that exceed crop requirements. Data can be used to determine remaining NPK crop requirements once animal livestock sources are accounted for. Indicates if there is potential benefit from the importation and application of organics into the system.	Generalised data from model is restricted by 2 km resolution. Agricultural Census grid square data is constructed as a scaled estimate from data collected at the Agricultural Parish level geography. http://agcensus.edina.ac.uk/agcen2.pdf Generalised data from model is restricted by 2km resolution. Agricultural Census grid square data is constructed as a scaled estimate from data collected at the Agricultural Parish level geography. http://agcensus.edina.ac.uk/agcen2.pdf
Name: 11_2015_Net_demand_surplus_Phosphorus/Phosphate Scale: 2 km Units: kg/ha			
Name: 12_2015_Net_demand_surplus_Potassium/Potash Scale: 2 km Units: kg/ha			

Table 3.5. Geospatial spreading risk

Data Set name and scale at which constraint has been mapped	Data source	Notes on data and how it can be used	Limitations to data
Name: 24_LCA_Spreading_Risk_Classification Scale:National Scale, 1:250000 equivalent	www.hutton.ac.uk/learning/natural-resource-datasets/landcover/land-capability-agriculture	Expression of risk for land-based spreading based on capability for agriculture. To determine risk to water quality from the land spreading based on three categories: • Low Risk includes LCA categories 1 – 5.2 • Medium Risk includes the narrow range of land that falls into LCA class 5.3 • High Risk includes LCA class 6.1 to 7	The main criteria used to classify risk is crop growth potential; higher risk areas have recognised crop production limitations due to climate and or landform. Land management strategies may be used to modify these controls.
Name: 25_Leaching_Potential Scale: National Scale, 1:25000 equivalent	www.spatialdata.gov.scot/geonetwork/srv/eng/catalog.search#/metadata/8eb71a80-044d-467d-a44a-879bbf6d2321 Lilly and Baggaley (2018a)	Map shows risk of organic pollutants and nutrients leaching through the soil or running off the surface and potentially impacting ground and surface waters. Map covers the cultivated land in Scotland. The soil leaching potential gives information on the likelihood of a potential pollutant that is applied to the soil surface infiltrating the soil and leaching to a water course or ground water in three main categories (High, Intermediate and Low) with the High class being subdivided into three classes and the intermediate class is subdivided into two.	Licencing:www.nationalarchives.gov.uk/doc/open-government-licence/version/3/ No limits on public usage Data does not cover all of Scotland
Name: 26_Soil_Runoff_Risk National Scale, 1:25000 equivalent	www.spatialdata.gov.scot/geonetwork/srv/eng/catalog.search#/metadata/ab89fb3c-14fa-4ec1-8cd2-f9811a61713d Lilly and Baggaley (2018b)	Map shows the risk of water flowing overland (runoff) carrying potential pollutants into water courses. The digital dataset gives information on the likelihood of a potential pollutant applied to the soil surface running off the land to a water course in three classes (High, Moderate or Low) and is based on fundamental soil characteristics such as depth to a slowly permeable layer, soil porosity and flow pathways through the soil.	

Table 3.6. Designated sites

Data Set name and scale at which constraint has been mapped	Data source	Notes on data	Limitations to data
Name: 27_ Designated_conservation_areas Scale: National	http://gateway.snh.gov.uk/natural-spaces/	Boundaries of the designated conservation areas in Scotland including SSSI, SAC, SPA and RAMSAR. Datasets contain the boundaries of the various protected areas in Scotland. Designation can be used to identify sensitive receptors and indicate areas where additional land spreading controls may apply	Data is regularly updated. Last update of datasets. 2019-11-27
Name: 28_ Secondary_designated_conservation_areas Scale: National	http://gateway.snh.gov.uk/natural-spaces/	Boundaries of the designated conservation areas in Scotland. NNR, NR, LNR, Country Parks	
Name: 29_ Tertiary_designated_conservation_areas Scale: National	http://gateway.snh.gov.uk/natural-spaces/	Boundaries of the designated conservation areas in Scotland. Biosphere and Biogenetic Reserves and World Heritage Sites.	

Table 3.7. Amounts of NPK produced annually across Scotland from livestock sources

Modelling result showing amounts of N,P and K produced annually across Scotland from livestock sources

Data Set name and scale at which constraint has been mapped	Data source	Notes on data and how it can be used	Limitations to data
Name: 07_2015_Livesatock_manure_supply_Nitrogen Scale: 2 km; Units: kg/ha	Model Result developed by Leinonen, et al., (2019) Leinonen, I; Eory, V. and MacLeod, M. (2019) Applying a process-based livestock model to predict spatial variation in agricultural nutrient flows in Scotland. Journal of Cleaner Production, 209: 180 – 189. The model used data inputs are based on 2015 census data.	Data set showing the plant nutrients (NPK) arising from livestock recorded as being present in the area. The model provides an estimate of the “actual” amounts of nutrients arising from livestock sources. The model takes into account the impact of imported farm feeds and assumes that nutrients remain local to where they arise. Data can be used to determine how much plant fertilisers are being generated locally from livestock sources.	Generalised data from model is restricted by 2 km resolution. Agricultural Census grid square data is constructed as a scaled estimate from data collected at the Agricultural Parish level geography. http://agcensus.edina.ac.uk/agcen2.pdf Data is based 2015 agricultural information and cannot be updated without base line modelling
Name: 08_2015_Livesatock_manure_supply_Phosphorus/Phosphate (both elemental P and P_2O_5 are provided) Scale: 2 km; Units: kg/ha			
Name: 09_2015_Livesatock_manure_supply_Potassium/Potash (both elemental K and K_2O are provided) Scale: 2 km; Units: kg/ha			

Table 3.8. Scottish Water sewage sludge: current (2018) and projected (2040) production (NPK) and locations for figures.

Data Set name and scale at which constraint has been mapped	Data source	Notes on data and how it can be used	Limitations to data
Name:: 13_Sewage_Sludge_sources_and_supply_Nitrogen_2018 Name: 14_Sewage_Sludge_sources_and_supply_Phosphorus_and Phosphate_2018 Name: 15_Sewage_Sludge_sources_and_supply_Potassium_and Potash_2018 Name: 16_Sewage_Sludge_sources_and_supply_Nitrogen_2040 Name: 17_Sewage_Sludge_sources_and_supply_Phosphorus_and Phosphate_2040 Name: 18_Sewage_Sludge_sources_and_supply_Potassium_and Potash_2040 Scottish Water sewage sludge production facilities. Scale: Point Data; Units: kg/ha	Provided by Scottish Water (2019)	Current (2018) and Projected production (2020) From Scottish Water facilities 2040. Scottish Water is projecting both a change in capacity and treatment process, giving rise to differing location and nutrient value. The current and expected production levels have been converted into NPK values Data can be used to understand and model where organic nutrient sources are arising spatially and to quantify them in terms of plant nutrient supply. Conversion to NPK values is based on reference values from TN650 - Optimising the application of bulky organic fertilisers (SRUC, 2013)	The 2040 data are projections only. Not all facilities shown in the data are currently or are projected to use land spreading as the main outlet for the nutrients that arise.

Table 3.9. Point sources of organic nutrients that can potentially be applied to land - AD and compost facilities

Data Set name and scale at which constraint has been mapped	Data source	Notes on data and how it can be used	Limitations to data
Name: 19_Location_AD_Feedstock_Types Name: 20_Location_and_Total_Potential_Energy_Production_AD_Plants Name: 21_Location_Composting_Facilities_Certified Scale: Point Data	Biofertiliser Certification Scheme website www.biofertiliser.org.uk/producers www.google.com/maps/d/viewer?mid=1Qf92NTQfp73mglljO7i9YdoOMKk&ll=57.87602626594907%2C-3.6628305947979243&z=9 www.wrap.org.uk/sites/files/wrap/Zero_Waste_Scotland_Digestate_Market_Development.pdf Above does not include Scottish Water sites.	This section includes farm-based, merchant and industrial AD plants, but not those treating biosolids, which are covered separately. The location of AD and compost Plants can be used understand the location and likely tonnage of digestate and composts being produced.	It is known that some plants transport their digestate a great deal further than this, whereas others manage to find landbank within a 30 km radius. The number of AD plants has increased rapidly in recent years and is still increasing. There may therefore be a few more AD plants than those included in the map (Figure 7.13). The tonnage and digestate type coming from each plant is not known. Amounts of plant nutrients (NPK) arising is also not directly known. It is not possible to know how accurately the site and feedstock type for the compost layer is.

Table 3.10. Point sources of organic nutrients that can potentially be applied to land - distillery and brewery locations

Data Set name and scale at which constraint has been mapped	Data source	Notes on data and how it can be used	Limitations to data
Name: 22_Distillery_Locations_Net_Capacity Name: 23_Location_of_Breweries Scale: Point Data	Biofertiliser Certification Scheme website Whisky Industry Review 2015 (www.scotchwhiskyindustryreview.com/)) ZWS (2015) Circular Economy Sector study on beer, whisky and fish. www.zerowastescotland.org.uk/sites/default/files/ZWS645%20Beer%20Whisky%20Fish%20Report_0.pdf	The location of distilleries can be used to estimate the likely volume of waste being produced, and this can be refined to an extent by taking into account the energy produced by some of the plants (which is known). The location of AD and compost Plants can be used understand the location and likely tonnage of digestate and composts being produced.	There is no comprehensive source of location data for the brewery and distillery sector. Also there is no reliable source of informant on how much organic waste is produced. Secondary indicators such as total potential capacity cannot be used reliable to understand the amount of spreadable material arising from these facilities.

Table 3.11. Economic modelling focusing of livestock markets and impact on livestock manure and slurry generation

Data Set name and scale at which constraint has been mapped	Data source	Notes on data	Limitations to data
Name: 30_2019BaselineLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: tonnes)	SG_NUTSLevel3_2008 (www.spatialdata.gov.scot/geonetwork/srv/api/records/4c8d00f2-0b46-4656-9d6b-c0d691918bd5) Also based on extrapolation from the June Census data 2015 adjusted pro –rata for changes in the national livestock population.	Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A baseline situation for the year 2019 based on historic 10 year trends	This data is limited by its local authority geography and the accuracy of calculations derived to anticipate tonnes solid manures and slurries produced from dairy and beef cattle, pigs, sheep, layers, broilers and breeding hens and other poultry under different conditions determined by the trading position of UK in future years.
31_2024NoChangeLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: tonnes)		Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK remains as of 2019. This is the prediction for the year 2024 based on historic 10 year trends	
32_2029NoChangeLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: tonnes)		Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK remains as of 2019. This is the prediction for the year 2029 based on historic 10 year trends	
33_2034NoChangeLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: tonnes)		Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK remains as of 2019. This is the prediction for the year 2034 based on historic 10 year trends	
34_2039NoChangeLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: tonnes)		Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK remains as of 2019. This is the prediction for the year 2039 based on historic 10 year trends.	
35_2024FortressUKLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: tonnes)		Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK is linked to the FAPRI-UK projections S5-WTO and DP rules This is the prediction. for the year 2024.	
36_2029FortressUKLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: tonnes)	SG_NUTSLevel3_2008 (www.spatialdata.gov.scot/geonetwork/srv/api/records/4c8d00f2-0b46-4656-9d6b-c0d691918bd5) Also based on extrapolation from the June Census data 2015 adjusted pro –rata for changes in the national livestock po	Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK is linked to the FAPRI-UK projections S5-WTO and DP rules This is the prediction. for the year 2029.	This data is limited by its local authority geography and the accuracy of calculations derived to anticipate tonnes solid manures and slurries produced from dairy and beef cattle, pigs, sheep, layers, broilers and breeding hens and other poultry under different conditions determined by the trading position of UK in future years.
37_2034FortressUKLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: tonnes)		Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK is linked to the FAPRI-UK projections S5-WTO and DP rules This is the prediction for the year 2034.	
38_2039FortressUKLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: tonnes)		Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK is linked to the FAPRI-UK projections S5-WTO and DP rules This is the prediction for the year 2039.	
39_2024FreetradeUKLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: tonnes)		Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK is linked to the FAPRI-UK projections S4-UTL and DP rules This is the prediction for the year 2024.	
40_2029FreetradeUKLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: Tonnes)		Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK is linked to the FAPRI-UK projections S4-UTL and DP rules This is the prediction for the year 2029.	

Data Set name and scale at which constraint has been mapped	Data source	Notes on data	Limitations to data
41_2034FreetradeUKLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset. Units: Tonnes)		Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK is linked to the FAPRI-UK projections S4-UTL and DP rules This is the prediction. for the year 2034.	
42_2039FreetradeUKLivestockManures_LA_Scotland.shp Scale: National- Data has been joined with the Local Authority geography dataset		Tonnes of solid and liquid manures produced annually from housed livestock. Figures modelled by SAC Consulting. A scenario where the trading position of the UK is linked to the FAPRI-UK projections S4-UTL and DP rules This is the prediction. for the year 2039.	

3.1 Potential land base for spreading

Under the Controlled Activities Regulations, specific land uses including urban areas, railways and forestry limit the land base that is available for spreading of organic and inorganic materials. A GIS layer for non-spreadable land was created that encompasses a number of publicly available data sets that were combined to exclude all areas of Scotland with recognised controls on the spreading of organic material. The main features that are included cover:

- Built up area, road and railway networks
- Surface water with appropriate buffer strips
- Woodlands

GIS layers were arranged and merged together to create a single layer that represents the Scottish geography that is now determined to be unsuitable for the spreading of organic material. The feature that has been mapped as no-spread has been retained and can be identified and mapped separately. The details of the features included, and the data sets used to create this layer are covered in Table 3.1. An example of the maps that can be generated using this data set at the national and inter-catchment scale is provided in Figures 7.1 and 7.2 (Appendix A).

Surface waters boundaries were obtained from Ordnance Survey Vector Map District (OS VMD) and included both standing and flowing water, including coastal waters. These are buffered to contain an area of 10m from water edges. Point locations for drinking water abstraction and the required no-spread buffer have not been included.

Urban settlements and rural buildings are derived from National Records of Scotland data and OS VMD buildings layer (NRS, 2020) (updated in 2018 from 2016 records). These are clustered with an aggregate distance of 50 m.

Road and rail surfaces are extracted from OS VMD. Roads are buffered to 7.5 m from the mapped road edge and rail is buffered 5 m from the track edge.

Woodland cover is derived from the Native Woodland Survey Scotland (minimum polygon size 0.5Ha) updated in 2017 and the Forestry Commission Inventory 2017 (GDS, 2020).

Figure 7.1 (Appendix A) shows a map of those areas of Scotland where there are legislative controls restricting the spreading of organic materials to land. Figure 7.2 (Appendix A) shows the same features at a much larger scale for the Pow Water catchment.

The data set can be used to show and calculate the land base that has no designated controls on the land spreading of organic materials over an area defined by the user.

The data set does not identify “agricultural land” and land management usages such as rural parkland and golf courses that would not typically be used for land spreading are not distinguished from agricultural land as there is no legal reason for their exclusion. Land spreading controls arising from the presence of point sources used for abstraction of drinking water or the presence of springs and wells have not been included.

An example of the application of this data set is provided in Appendix B.

3.2 The impact of slope on spreading

Based on a 50 m resolution, two national slope maps were created. The first shows slopes > 15° and reflects areas of agricultural land where slope should be a consideration when applying organic materials (Table 3.2 and Figure 7.3, Appendix A). The second shows areas with slopes > 25^o which have implications for the land spreading of organics to support forestry and agricultural production. (Figure 7.4, Appendix A). These maps are discussed in further detail in Section 1.2.3. Slope and topography.

Having a separate GIS layer for slope and topography to exclude areas unsuitable for spreading may be beneficial at smaller scales where LCA/LCF classification is too coarse to show the effects of variations in slope/topography.

LCA classification does contain slope in its construction but the categories are also determined by other factors such as soil depth, drainage capability etc. and as such slope is not independent and distinguishable as a separate factor.

The outer limits, shape and depth of manmade features that occur in the baseline data include mineral extraction and landfill sites and are included to meet positional accuracy requirements. Temporary features that do not represent the terrain at the time of capture, for example spoil heaps, are removed from the data.

Note that the digital format for more extensive sites (such as opencast coal sites) are surveyed in OS terrain data. However, OS paper maps do not show contours for these areas, so they could be not included in this dataset.

When using this data set, the coarse resolution of the digital terrain model that was available (50 m) has to be considered as only those areas with pronounced and extensive slopes will be included.

3.3 Crop nutrient dynamics

The main justification for the spreading of organic materials to agricultural land, particularly those obtained from outside the farm, is to provide nutrients to support crop production. Their use is only justifiable if there remains a net crop demand for additional fertiliser based on standard practice, once the spreading of manure and slurries that arise on the farm have already been taken into account. Imported organic materials do have the potential to displace manufactured fertilisers but this should not be assumed.

The objective of this data set was to provide a measure of the crop fertiliser requirements across Scotland and to understand the scale of the nutrient demand after the indirect (grazing livestock) and direct spreading of livestock manure and slurries has been accounted for. The process-based model developed by Leinonen, *et al*. (2019) was adopted as it provides a nationwide assessment of “actual” nutrient usage based on the June 2015 Scottish Agricultural Census.

In their work they estimated the “actual” nutrient demand, i.e. the actual fertiliser application rate used to cover the removal of nutrients in harvest and losses to the environment based on actual practice rather than the biological potential of the crop. The model also takes account of the nutrient value of manures and slurries that are arising on the farm unit and uses this to partially (or fully) account for the crop nutrient requirements.

This data set has a 2 km resolution and details on the data layers generated are provided in Tables 3.3, 3.4 and 3.7 and detailed below.

3.3.1 Plant nutrients from livestock manures and slurries

Three data layers (Table 3.7) have been provided that show the amount of N, P and K that is being generated from livestock based on the descriptors used in the 2015 Agricultural

Census. The model (Leinonen *et al.,* 2019) then uses this to generate NPK excretion using the Scottish Agricultural Emission Model (SAEM). Users of this data set should understand the following:

1. The estimates of livestock excretion are based on actual livestock numbers and types. This is ascribed a spatial value using the data averaging algorithms used by the 2015 Agricultural Census.

2. The use of SAEM has provided a mechanism to account for the nutrients imported into the agricultural system from bought in feed.

3. The spatial scale of the data set is 2 km^2 due the nature of the 2015 Agricultural Data census data and this should be taken into consideration during its use.

4. The values represent total excretion during both grazing and housing periods.

3.3.2 Crop demand

Three data layers (Table 3.3) are provided that show the crop requirement for N, P and K based on the Leinonen *et al.* (2019) model. The key factors that uses should take account of are:

1. The crop demand is derived from "actual" fertiliser usage (both organic and manufactured) in kg/ha using information from the 2015 Agricultural Census that provides a spatial record of the types of crop grown across Scotland and estimates of actual yield. This has then been combined with the British Survey of Fertiliser Practice (Defra; 2019a) to derive a model of actual fertilisation practices across Scotland.

   The spatial scale of the data set is 2 km^2 due the nature of the 2015 Agricultural Data census data and this should be taken into consideration during its use.

3.3.3 Net crop nutrient demand

Three data layers (Table 3.4) are provided that show crop demand for NPK and the nutrients supplied by animal livestock to give a net nutrient demand. The key factors that users should take account of are:

1. It is assumed that nutrients that arise from livestock in a given spatial area are used for crop production in the same area and are distributed equally.

2. Negative numbers have been allowed and their occurrence indicate a net crop demand i.e. the amounts of plant nutrients derived from livestock manures within the area is not sufficient to meet crop demand and will need to made up with application of bagged fertiliser or by importing off farm organic sources.

2. The spatial scale of the data set is 2 km^2 due the nature of the 2015 Agricultural Data census data and this should be taken into consideration during its use.

An example of one data set showing net P crop demand at a national scale has been provided in Figure 7.5. (Appendix A) and the same results at an inter-catchment scale for the Pow Water is shown in Figure 7.6 (Appendix A). An example of the livestock manure supply

for P is shown in Figure 7.7 (Appendix A) and an example of fertiliser crop demand for P is shown in Figure 7.8 (Appendix A).
Additional information on fertiliser crop demands, livestock manure supplies and resulting net surplus demand can be found in Tables 3.3, 3.5 and 3.7.

Nationally the trends in the 2 km resolution data are predictable with most of the North West having a small net demand for P. In the central belt, southern Scotland and in Ayrshire there are areas of net surplus due, primarily, to localised areas of intensive poultry and dairy production. The main areas of net demand are along the East coast reflecting the arable production in this region and the lower livestock density. Similar trends are found for N and K demand (data not shown).

3.4 Spatial availability of nutrients from organic fertiliser sources

As discussed in Section 1.2.4, the cost associated with transportation and spreading of bulky organic materials affects the extent of the land base that can, cost effectively, be used for land spreading.

As part of this study the specific locations of some of the most recognised sources of organic material that is spread to land have been mapped. In the case of sewage sludge it has been possible, due to the high quality data provided by Scottish Water, to calculate the actual amount of N, P and K arising from sludge sourced from different treatment plants. For other sources such as digestate, distilleries and compost only proxy indicators such as net potential production of product or energy are included where available. It is recognised that the proxy indicators cannot be used to accurately estimate the amounts of plant nutrients that are actually available from these sources.

The intention of this data set is to allow users to identify all sources of nutrients available for land spreading within a target area. It should also help to identify areas where large amounts of materials are being generated, and in turn, enabling situations where potential over-application could occur to be highlighted.

Three principal sources of organic fertiliser were assessed to understand the location and volume of material arising across Scotland; sewage sludge (Section 3.4.1); distillery and brewery by-products (Section 3.4.2); and anaerobic digestates and composts (Section 3.4.3).

3.4.1 Sewage sludge

Scottish Water has provided estimates of its current and projected (2040) sewage sludge generation from each treatment plant across Scotland (Scottish Water, pers. comm.). In addition, they have estimated that they target ~ 30 km spread radius zone around each facility that produces or treats sewage sludge which is spread to land (Table 3.8).

The Scottish Water current and projected sewage sludge production figures were transformed into estimates of N, P and K supply based on the treatment process descriptor and values for N, P and K contents in SRUC Technical Note TN650 (Optimising the application of bulky organic fertilisers, SRUC; 2013).

Based on this, 6 data sets were generated showing the location and supply of key nutrients (N, P and K) currently (2018) and projected future facilities in 2040.

Scottish Water is predicting a net increase in the amount of sewage sludge produced (dry tonnes) nationally by 2040 but due to changes in the treatment process this will result in a net decrease in the N, P and K provided to land from sludge spreading.

The current location and P production levels from sewage sludge treatment works (based on a 30 km diameter radius) are shown in Figure 7.9 (Appendix A) and the future estimates in Figure 7.10 (Appendix A) show that there will be a number of facility closures and a centralisation of treatment and therefore land spreading intensity. Figure 7.10 (Appendix A) illustrates how the geo-spatial tool could be used map nutrient loading across all organic materials applied to land. It does not show how material is currently being spread.

The location and production capacity of sewage sludge will provide a direct tool to understand organic nutrient availability and risk at a local level.

3.4.2 Distillery and brewery by-products

Based on the Scotch Whisky Industry Review (2015), the location and net production capacity (litres per annum) of distilleries and breweries across Scotland was collated to generate a data set (Table 3.10).

There is no reliable means of estimating the amount of nutrients arising from the distillery sector that are directly spread to land. Individual distilleries do not publish this information and differing onsite processing and disposal routes make the interpretation of production capacity figures unreliable. In addition, many distilleries are installing anaerobic digestion plants to treat waste outputs, which changes the characteristics, volume and waste status of these outputs.

Assuming that there is a relationship between production capacity and the amount of N, P, K that is, or may be, available for land spreading, a data set was created (Table 3.10) that shows location and net production capacity (product) based on the 2015 Scotch Whisky Industry Review (2015). A map of the location and production capacities of relevant facilities is shown in Figure 7.11, Appendix A).

There is also no publicly available dataset that can provide any insight into the amount or nutrient values of brewery by-products being either spread directly to land or fed to livestock. The location of breweries is an important consideration and a data set (Table 3.10 and Figure 7.12; Appendix A) was generated based on a 2015 study on the sector (ZWS, 2015) but no associated data is available that gives any insight into their production capacity or the amount of material that is spread to land.

3.4.3 Anaerobic digestates and compost

Based on publicly available information the location, feedstock type and total potential energy output of Scotland's anaerobic digestion plants can be mapped (See Table 3.9 for references). The number of assumptions that are required to convert potential energy production into amounts of N, P and K produced are too variable to allow a direct conversion. The location of known AD plants is mapped based on feedstock type (Figure 7.13; Appendix A) and net energy production potential. (Figure 7.14; Appendix A). The net energy has been included as an assumptive indicator of potential nutrient output only and it recognised that it is of limited use.

Some information is available on the location and feedstock type of composting facilities across Scotland (Table 3.9 and Figure 7.15; Appendix A). This information is restricted to facilities that have registered under the Bio-fertiliser accreditation scheme but does not include any details on their current status, volume produced, quality or primary end usage of the compost.

There were no publicly available data sets that show, with any accuracy, the production capacity of compost facilities across Scotland.
The lack of current, direct, and detailed information on the amounts of digestate and compost being produced creates a significant problem with using this data set. In its current form its only application will be as an indicator of a potential source of nutrients in a given area.

3.5 Land classification

As discussed in Section 1.2.1, all of Scotland's land areas have been classed into one of 7 Land Capability for Agriculture (LCA) classes. For this study, the LCA has been simplified and mapped into three categories to express where land spreading of organics will be the most beneficial (Table 3.5 and Figure 7.16; Appendix A). Low risk indicates area with good yield potential and land spreading of organics is more justifiable. High risk areas are those where yield potential is low and land spreading is less justifiable.

To express land spreading potential in relation to LCA a map was created that classified LCA in to three categorises.

1. Low risk includes LCA categories 1 – 5.2 as this encompasses land this is recognised as having the potential to produce high yielding crops and the application of organic fertilisers is likely to be of direct benefit.

2. Medium risk includes the narrow range of land that falls into LCA class 5.3. This land has the potential to be used as improved grassland but will need careful management to achieve average yields and is more likely to not effectively make use of applied nutrients.

3. High (or unacceptable) risk includes LCA class 6.1 and higher as land has very limited potential to achieve increased yields in response to the application of organic fertilisers. Land in this LCA range is also likely to be considered as Rough Grazing for the purposes of subsidy applications and should not be spread with organic or inorganic fertilisers.

The above categories were mapped into a single GIS layer to express the potential for land spreading based on LCA.

The original LCA classification contains a descriptor that indicates why a given area of land was allocated to a class. Unfortunately, the digital version of the system does not include this descriptor. In future, such descriptors could be included to provide a more accurate means of assessing the impact of LCA class on the landbank for spreading of organic materials.

3.6 Soil risks

The soils across Scotland have been comprehensively surveyed by the Macaulay Institute (now part of the James Hutton Institute) from the 1940s until the 1980s (Lilly and Baggaley, 2018a; 2018b) and this survey has been used to create a series of risk maps for the main cultivated areas of Scotland, which have been included in this data set. There are two layers that have relevance to land spreading of organic materials. The first is Leaching Risk which classifies soils based on the relative risk of surface applied material transferring directly by leaching to ground and surface water (Lilly and Baggaley, 2018a). The second is a classification of surface runoff risk which reflects the likelihood of the soil becoming saturated, potentially leading to liquid flowing over the land (Lilly and Baggaley, 2018b).

These data layers currently only provided an indication of risk to water quality and in their current form provide limited insight. It is envisioned that more advanced applications of this entire data set will make use of these layers to better categorise spreading risk.

A third data set has been included that maps the Soil Phosphate Sorption capacity of Scotland's soils soil resources (Figure 7.17; Appendix A) (SRUC, 2015). This provides an estimate of the capacity of soils to bind soil P and has been created to help determine the amount of P that is required for a given soil to reach the target soil P status for the crops grown in it.

3.7 Nitrate vulnerable zones

Scotland has designated areas where agricultural use of N has been identified as posing a risk to ground water quality (See section 1.2.9). Within Nitrate Vulnerable Zones (NVZs) (Figure 7.18; Appendix A) farmers must comply with rules on the amount and timing of N applications. These areas have been included in this data set as the regulations include controls on the total amount of N, from both manufactured and organic sources, that can be applied as well as controls over when they can be applied (closed periods).

Limiting the total amount and timing of N that is applied to land is the legal responsibility of the land manager and they must use specific N availability factors for each organic material used.

In its current form the application of this data set to understanding spreading risk is limited to identifying areas of Scotland where closed periods apply. More advanced applications of the full data set will make use of this designation to make it applicable to understanding direct limits on spread rates, particularly as greater insight is gained into the relationship between N and P.

3.8 Designated conservation areas

Scotland's designated areas have a range of differing levels of protection and land management controls applied to them. Any specific controls on either the type or amount of organic materials that could be applied within their boundaries would be subject to a local management agreement and not publicly available. The designation type and boundaries are, however, relevant as they indicate that additional controls on land spreading may exist that extend beyond standard regulatory controls. These have been included in the data set in three layers.

One layer includes all primary designated conservation areas such as SSSI, SPA, SAC and RAMSAR, the other two include secondary and tertiary designated conservation areas as described in Table 3.6.

4 Assessment of current and predicted future quantities of waste-derived materials that can be used sustainably on land

4.1 Introduction

This section presents key points and conclusions from the first three chapters in the report and considers the value and limitations of the work done to date. It then addresses the fundamental question from the project as a whole: "Is there sufficient landbank now and in the future for the safe, sustainable and beneficial use of all of the materials (as defined in this project) produced in Scotland."

4.2 Factors affecting the application of materials to land

Twenty factors affecting the application of materials to land were considered in Section 1. These included physical, land management, seasonal, climatic and economic factors, along with legislative controls and good practice guidance. Compliance with some of the controls was compulsory in some or all cases (e.g. under the NVZ, CAR and Sludge [Use in Agriculture] regulations). Compliance with many of the controls represented a legal requirement (e.g. application of nutrients to match crop demand) or best practice. The impact of some of the controls, such as those provided in farm assurance scheme rules or stated in buyer preferences, result in working practices which do not necessarily have significant impacts on soils, crops or the environment but which are important for a range of other reasons for those to whom they apply.

Some of the factors represent major controls over spreading in one or more land uses in that they have a significant impact on the landbank for one or more materials, whereas others have relatively minor impacts. Table 4.1 summarises the existence of legislation and good practice guidance in relation to the factors under consideration and summarises the relative importance of each in terms of its impact on landbank in Scotland. An assessment of the extent to which each factor assessed effectively controls risks and maximises the benefit of land applications is also made (where relevant), along with a judgement as to whether the beneficial impact of the factor (including legislative controls) could be improved. These topics are further discussed in Sections 4.2.1 to 4.2.20.

Table 4.1. Summary of the factors affecting the application of materials to land (✓= yes; X = no, N/A = not applicable)

Factor[1]	Is there relevant legislation				Is there effective good practice guidance				Impact of factor on availability of land for spreading[3]	Does factor effectively control risks and maximise benefit of land applications?	Could beneficial impact of factor be improved?
	Ag[2]	F	Am	Br	Ag	F	Am	Br			
Land Capability	X	X	X	X	✓	✓	X	X	major	not applicable (N/A)	N/A
Seasonal and climatic factors	✓	✓	✓	✓	✓	✓	✓	✓	major	not always	a lot
Slope and topography	✓	✓	✓	✓	✓	✓	✓	✓	major	generally, yes	no
Distance from landbank for organic materials	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	major	N/A	N/A
Soil type and soil properties	✓	✓	✓	✓	✓	✓	✓	✓	major	not always	yes
Proximity to water bodies (related to slope, topography and land management)	✓	✓	✓	✓	✓	✓	✓	✓	moderate	generally, yes	yes
CAR GBRs covering diffuse pollution	✓	✓	✓	✓	✓	✓	✓	✓	major	generally, yes	a little
Crop nutrient requirements (linked to land use and land management)	✓	✓	✓	✓	✓	✓	X	✓	major	generally, yes	yes
Controls on N loading rates within and outside NVZs	✓	N/A	N/A	N/A	✓	✓	N/A	N/A	major	generally, yes	no
P loadings	✓	X	X	X	✓	✓	X	X	major	no	yes
Competition between different materials, particularly those from agriculture	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	geographically dependent	no	yes
Controls in the Sewage Sludge (Use in Agriculture) Regulations (1989)	✓	N/A	N/A	N/A	✓	✓	N/A	✓	major	generally, yes	yes
Controls under Waste Management Licensing Exemption rules	✓	✓	✓	✓	✓	✓	✓	✓	major	variable	yes
Risk of pathogen transfer to food crops and water bodies	✓	✓	✓	✓	✓	✓	✓	✓	moderate	generally, yes	a little
Controls on designated sites	✓	✓	✓	✓	✓	✓	✓	✓	moderate	N/A	N/A
Farm QA Scheme rules and produce buyers rules	N/A	N/A	N/A	N/A	✓	N/A	N/A	N/A	as above	yes	yes
***Organic Farming regulations** and rules*	✓	-	-	-	✓	-	-	-	major	yes	yes
Requirement for nutrients/organic matter in land restoration	N/A	N/A	N/A	✓	X	X	X	X	major	no	yes
Cost of materials (financial acceptability in different sectors)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	major	no	yes
Carbon footprinting	X	X	X	X	X	X	X	X	potentially major but not important at present	no	yes

[1]Ag=agriculture; F=forestry; Am=amenity; Br=brownfield; [2]***Factors in bold italics in shaded boxes represent legislation**, those in non-bold italics in shaded boxes are managed to some extent by relevant legislation.* [3]The impact of each factor on availability of land for spreading has been categorised as minor, moderate or major, based on expert assessment of all relevant information considered in Sections 1.2.1 to 1.2.20.

4.2.1 Land capability

Given that there are relatively limited or no opportunities for spreading materials to land in classes 5.3 and above, and these cover around 60% of Scotland's land area, land capability is arguably the greatest single factor affecting the application of organic and other materials to land in Scotland.

There is no relevant legislation covering land capability for agriculture, forestry, amenity or brownfield land. However, there is good information on land capability for agriculture and forestry and clear interpretation of the different land capability classes. That information is useful for farmers, land managers and specialist consultants working with organic materials. It can also be useful for those planning creation of amenity sites and restoration of brownfield sites, because it can give an idea of the type of land use and cropping which could be possible on sites of a given altitude, slope and aspect. In this project, Scotland's land area was divided into low risk for spreading (classes 1 to 5.2), medium risk (class 5.3 and high (or unacceptable) risk (class 6.1 and above). This has been clearly set out in the GIS dataset (see Section 3.5).

Risk in relation to the LCA system encompasses a number of factors, but two important ones when assessing the potential for spreading on land with an LCA > 5.2 are:

1. The yield response that would be expected from the application of organic nutrients either cannot be reasonably expected or would be of little net benefit to the farming system.

2. The actual process of applying bulky organic nutrients to the land would pose a significant risk of damaging soil, water and broader environmental quality due to topography or drainage conditions.

On saying that, there is evidence that Scotland's climate is changing and some models predict that the areas suitable for arable crops are likely to increase, thus increasing the area suitable for spreading organic and other materials. The LCA and LCF systems will have to be updated if they are to be used to understand the inherent limits on land spreading both now and in the future. It is understood that work is underway in this respect at the James Hutton Institute.

4.2.2 Seasonal and climatic factors

Seasonal and climatic factors *should* determine whether bulky fertilisers and soil conditioners should be applied at a particular time and they represent a major factor affecting the application of materials to land.

Several key pieces of legislation are in place to enforce good practice in some situations. These include the NVZ, CAR, Sludge [Use in Agriculture] regulations and exemptions to the Waste Management regulations. There is also excellent good practice guidance for all sectors. However, there is considerable anecdotal evidence of bad practice, particularly in agriculture, and particularly with application of high RAN liquids, which are being applied at inappropriate times of year, when there is little or no crop demand and when the weather is poor. The problem is known to be particularly severe in areas where large volumes of manures and slurries are being produced (e.g. areas with large amounts of intensive livestock production) or where anaerobic digestion facilities are producing whole or liquid digestates and have inadequate storage.

Where high RAN liquids are applied at appropriate rates, but at inappropriate times of year or in poor weather, the risk of N losses to the environment are higher. This obviously has a financial implication for those using the materials, as well as greenhouse gas implications. There are other potential risks to water quality too, such as from faecal indicator organisms and to biological oxygen demand. Not only is there a risk (to air quality) from nitrous oxide and ammonia emissions associated with application of organic fertilisers in wet weather, there is also the carbon dioxide emissions associated with wasted diesel and the manufacture of synthetic fertiliser (required to make up the balance of required N following the losses) to consider.

Currently LCA remains the best available data set to systematically inform us of limitations to spreading (in agriculture) due to climate. Land of class > 5.3 has been classed as high risk in the GIS data set due, in part, to climatic factors.

There is continued need for improved knowledge exchange between AD plant managers, farmers and other land managers to help them better understand the risks associated with applying high RAN liquids as well as solutions to the problems which applying them at inappropriate times can bring. Improved knowledge exchange is a key recommendation across many of the topics covered in this report. For that reason, it is not discussed further in Section 4. Detailed recommendations are covered in Section 5.

4.2.3 Slope and topography

Slope and topography frequently determine whether bulky fertilisers and soil conditioners can be safely applied or not and as such, they represent a major factor affecting the application of materials to land. The CAR regulations are in place to enforce good practice in spreading materials on land. In particular, they aim to prevent harm to water quality, and there is excellent supplementary guidance associated with this legislation, which is relevant to all four of the sectors under consideration (SEPA, 2019a).

All of Scotland's spreadable land base is sloping toward a water body either directly or indirectly. Steeply sloping land (i.e. that with slopes steeper than 15^o) poses a clearly identifiable risk to water quality where materials are spread on this land. SEPA suggest that slopes steeper than 12 degrees) are very steep slopes where run-off is a high risk throughout the year. In addition, lower angled slopes may also be a risk depending on land, soil and weather characteristics and proximity to watercourses. (M Aitken, pers. comm.). The GIS dataset developed for this project provides the beginnings of a system to evaluate the connectivity between land and water receptors, since the steepness of any slope is only one element of the risk in spreading materials on sloping land.

Given that there are relatively limited opportunities for spreading materials to land with slopes steeper than 20^o and above, and these cover around 6% of Scotland's land area, slope and topography (which are included to a large extent in land capability classifications) are (rightly) a significant barrier to applying organic and other materials to land in Scotland. There is nothing that can be done to mitigate this, therefore this barrier will remain.

4.2.4 Distance from landbank for organic materials

Distance from landbank presents a significant difficulty for producers of organic wastes in some locations and is therefore a major factor affecting the application of certain types of materials to land in some parts of Scotland.

Distance from landbank is particularly problematic for distilleries, breweries and those producing digestates, composts and biosolids and is a critical concern where the producers are based in large urban locations. Whilst there is legislation and good practice guidance in place to help ensure that organic materials are spread with maximum benefit and minimum risk, there is considerable anecdotal evidence that materials are sometimes spread at inappropriate times and in poor weather and/or soil conditions. Farmers in Scotland are still being offered (or have their own) high nutrient liquids to use when there is no crop demand and there is inadequate storage in place to hold these liquids until the opportunity arises to spread in appropriate conditions. This is mostly a problem with high RAN liquids rather than solid materials such as composts, fibre digestates or biosolids, but it also occurs with other liquids (M. Aitken, pers. comm.).

There is also evidence that some materials (including both liquids and solids) are transported for long distances in order to secure sufficient landbank prepared to take them. Such transport is often extremely costly and in the case of digestates is only possible due to the subsidy gained through renewable energy generation. Long distance transport is not only undesirable because of the high cost, but also due to the hidden cost of greenhouse gas emissions associated with that transport. Should a carbon tax be introduced, or should effective, full life cycle analysis (LCA) carbon footprinting of renewable energy facilities and farms be introduced, then long distance transport of bulky organic materials will become cost-prohibitive and would mostly stop unless other disposal options are more costly.

The GIS dataset now represents the most up to date inventory on the point locations from which organic materials are arising in Scotland. It can be used to develop and implement models to assess the impact of current and future locations of plants producing bulky organic and inorganic wastes and products. The point origin of current and proposed sources of organic materials can now be used as a management tool to help protect water quality.

A less costly option for liquid organic fertilisers rather than transporting them a long way to landbank (and for some with landbank close by) is to de-water them and convert them into fibre products or inorganic fertilisers, which are more valuable, easier to store and cheaper to transport. In many cases, the liquid fraction is then disposed of in sewers, rivers and to the sea, which may result in a degree of environmental risk and also results in the loss of nutrients which would be better used for agricultural benefit. SEPA wish to encourage industrial process managers to look for the best possible use for their wastes, by-products and products (SEPA, 2019b). For example, materials may best be used as raw materials for other processes rather than as fertilisers for land application. Many AD plants and other commercial companies are currently attempting to improve the technologies which remove the water from the digestate and it is likely that more efficient, cost-effective technologies of this type will be available in the near future.

4.2.5 Soil type and soil properties

Soil type and soil properties *should* help to determine how and when bulky fertilisers and soil conditioners are applied for maximum benefit and minimum risk. If the values for some parameters are sufficiently high (e.g. soil phosphate, soil PTE concentrations) or low (e.g. pH) then regulatory controls should effectively restrict the application of materials to that land.

Both the CAR and NVZ regulations aim to enforce best practice in some situations, and there is good practice guidance for all sectors. There is little anecdotal evidence of bad practice, although it may occur, most likely when bulky organic fertilisers (particularly high RAN liquids or high-P materials) are over-applied to sandy, shallow or compacted soils.

The GIS data set developed in this project brings together all the spatial information on soil type and properties that is currently available in Scotland. Resources such as the phosphorus sorption capacity of Scottish soils (Scotland's soils, no date[d]), combined with the point locations of sources of high P organics could be used to ensure that the capacity of local soils for nutrients, given the nutrient requirements of crops grown, match the outputs from these point locations.

4.2.6 Proximity to water bodies (related to slope and topography)

Proximity to water bodies *should* determine where bulky fertilisers and soil conditioners should and should not be applied. This represents a major control over the application of materials to land.

Several key pieces of legislation are in place to enforce good practice in some situations. These include the NVZ, CAR, Sludge [Use in Agriculture] regulations and exemptions to the Waste Management regulations. There is also excellent good practice guidance for all sectors. There is a small amount of anecdotal evidence of bad practice, particularly in agriculture where slurries and manures are applied too close to rivers and ditches.

The spatial information on “no-spread” zones provided in the GIS dataset includes the legally binding no-spread buffer strips around watercourses. It provides an empirical tool to understand the limitations on the potential land base for spreading. In theory there is an enhanced risk to water quality in some areas of Scotland based on “hydraulic connectivity” between landform, management and a given receptor water body. The GIS data set has, for first time, brought together a number of data sets needed to better understand these linkages.

4.2.7 Controlled Activities Regulations (CAR) General Binding Rules (GBRs) covering diffuse pollution

Although the CAR regulations control the application of organic (and other) materials to land, they also make sound environmental and economic sense because they help to prevent loss of nutrients to water courses and ground water (and therefore also financial losses for land owners).

The GIS data set has, for first time, systematically mapped all legally binding “no-spread” areas of Scotland. These include the regulatory buffer strips required by the CAR regulation around water bodies but also include urban areas, forestry and roads. At the inter-catchment scale, this can be used to visually and empirically evaluate the spreadable land base in relation to point source of organic materials.

There is plenty of excellent good practice guidance available, particularly for farmers and foresters, and it has been widely publicised at workshops, conferences and seminars. Whilst there is some evidence of poor practice, particularly in relation to the spreading of organic materials too close to watercourses or in excess of the nutrient needs of crops, the authors are not aware that serious, frequent breaches of the CAR regulations are common in agriculture, forestry, amenity or brownfield land. It is thought that the combination of the regulations and good practice guidance are helping to ensure that organic and other materials are applied to land responsibly.

4.2.8 Crop nutrient requirements (linked to land use and land management)

Crop nutrient requirements *should* perhaps be the major determinant of the amount of nutrients applied to land in the form of fertilisers and organic materials. To a large extent they are, and they are rightly a major factor affecting the application of materials to land. Several key pieces of legislation aim to enforce good practice, including the NVZ, CAR and exemptions to the Waste Management regulations. Cross-compliance rules, Biosolids Assurance Scheme and Farm Assurance Scheme rules and Organic Farming Standards also play a role in some cases.

There is excellent good practice guidance to assist land managers, particularly in agriculture and forestry and particularly relating to the use of animal manures, composts and digestates (for example, SRUC 2019, 2013; WRAP 2017a, 2017b). There is perhaps a lack of published good practice guidance aimed at helping land managers use materials such as biosolids and the more unusual wastes, such as gypsum, mushroom compost and distillery wastes. Perhaps the greatest potential for over-application of nutrients, and the resultant risks to soils and water courses is in brownfield restoration, where there has been a history of applying very high tonnages of organic materials in “one-off” applications. Excessive nutrient applications are also sometimes made in small-scale horticultural enterprises (particularly vegetable production facilities) but these are very small in size and are unlikely to cause widespread environmental problems.

The GIS data set includes modelled estimates of the residual crop demand that can be met through the land spreading of organic nutrients (Table 3.4). Importantly, these net crop demands already take into account the nutrient values from manures and slurries that are arising in the farm system and have already been spread. The result is the net annual total capacity (in kg/ha) of the spreadable land base which is able to accept off-farm organic sources of N, P and K.

It is thought that the combination of the regulations and good practice guidance are helping to a considerable extent to ensure that crop nutrient requirements are met without being exceeded.

4.2.9 Controls on N loading rates both within and outside Nitrate Vulnerable Zones (NVZs)

The NVZ regulations are a major control over the application of organic materials (particularly high RAN liquids) in agriculture and some amenity situations. However, like the CAR regulations, they often make sound environmental and economic sense because they can help to prevent costly loss of nutrients to water courses and ground water. They are unpopular with many farmers, some of whom don’t realise that those who fail to adhere to the closed spreading periods can sometimes incur substantial losses of both N and money!

There is plenty of excellent good practice guidance available for farmers and it has been widely publicised at workshops, conferences and seminars. Whilst there is some evidence of poor practice, particularly in relation to the spreading of organic materials in closed periods and in the siting of manure heaps, the authors are not aware that serious, frequent breaches of the NVZ regulations are common in agriculture. The regulations are not applicable in forestry, amenity or brownfield land.

The GIS data set includes model estimates for the total and net N requirements for all of Scotland (Tables 3.3 and 3.4). For the first time, it is possible to evaluate and identify, at a meaningful scale (catchment and inter-catchment), those areas of Scotland where excess N from organic sources is arising.

It is thought that the combination of the regulations and good practice guidance are helping to a considerable extent to ensure that organic and other materials are applied to land responsibly in NVZs. There is a strong environmental and financial argument for increasing the agricultural area of Scotland included in NVZs, or perhaps more appropriately establishing closed periods for high RAN organic materials across all of Scotland. This is because there is clear anecdotal evidence that high RAN liquids are being applied to land when weather conditions are unsuitable and when there is no crop demand. This is happening in livestock, mixed and arable farms and is particularly common in intensively farmed land or near to AD plants or distilleries.

4.2.10 P loadings

Crop nutrient requirements *should be* the major determinant of the amount of P applied to land in the form of fertilisers and organic materials. To a large extent they are, and crop P requirements are rightly a major constraint to the application of materials to land. The legislation and good practice guidance aiming to prevent P loadings being too high is as for other major nutrients (see Section 4.2.8). Evidence from SAC soil test data suggests that the number of farms where P has been over-applied is likely to be low (SEPA, 2018b; FAS, 2019). Where over-application has occurred, it is likely to be in intensive livestock areas or near to biosolids production or potentially other types of facilities such as waste treatment plants. Certainly, unpublished data from SEPA audit sampling of soils at spreading locations have shown that land repeatedly treated with biosolids often does have P concentrations which are above target (A. Cundill, pers. comm.).

Given that the total land area in Scotland which is above P target and therefore has little or no annual demand for P is likely to be low, high soil P status is unlikely to have a significant impact on the land available for spreading organic materials to land overall. However, high soil P status is likely to be a significant barrier to land applications in certain localised areas of Scotland, such as in intensive agricultural areas and around biosolids production facilities. For this reason, national modelling of P availability versus P demand is likely to be of little use. Such modelling is likely to be useful only on a catchment scale or in the economical spreading area of individual point sources of P-rich materials.

The GIS data set provides estimates of the amount of P; arising from livestock sources, required by crops and the total net annual crop requirement that can be met from imported organic sources at the catchment and inter-catchment scale. This can now be combined with other data sets such as soil P sorption capacity and point locations of organic sources to understand and identify areas where soil-mediated risks arising from P applications are posing a quality risk to specific water bodies.

Regulations governing P loadings to brownfield land (including land restored for agriculture, amenity or forestry) are weak. Despite the CAR regulations being relevant in these sectors, extremely high P applications have been made in the past, in line with practices common at the time (and best practice guidance, e.g. SNIFFER, 2010). Current (unpublished) instructions from SEPA to apply no more than 2,000 kg/ha of phosphate during restoration of opencast for forestry or agriculture may be insufficient in some situations and there is a clear need for further work to determine best practice for applying organic materials to land in terms of P loadings.

4.2.11 Competition between different materials, particularly those from agriculture

Competition for landbank presents a significant difficulty for some producers of organic wastes in some locations and can create problems for those looking for cost-effective markets for some wastes and products.

The issue is particularly problematic for distilleries, breweries and those producing digestates, composts, and biosolids in locations where farmers have an abundance of their own manures and/or where there are several large AD plants and distilleries in relatively close proximity. Although liquid anaerobic digestates and distillery effluents can be good fertilisers, many land managers and agronomists feel that using them can be more hassle than it is worth unless they are able to access them at a significantly lower cost than manufactured fertiliser alternatives. Farmers in particular complain about the damage caused to soils by heavy tankers when they are asked to take digestate when there is little or no crop demand, when soils are wet or when the contractor is free (rather than at a time that suits them).

The GIS data set has provided all known point locations where significant amounts of organic phosphate are arising. Using relatively simple GIS modelling tools, it is now possible to understand the actual socioeconomic spreading "footprint" of these point sources. The additional GIS data sets also allow for the exclusion of non-spreadable areas within this footprint and provide insight into actual net crop demand that will limit potential spreading rates and where footprints overlap with other facilities.

There is clear evidence that developers of some Scottish plants producing digestates and other drinks wastes have failed to adequately assess local availability of landbank for their outputs prior to the plants being built. This is evidenced by the number of times during the past decade that the author of this section (and others in her company) have been called in to find landbank quickly for relatively new AD plants which have full tanks and nowhere for the digestate to go. Landbank studies for proposed new facilities should estimate annual tonnages of all "competing" organic and inorganic materials originating from other local existing facilities. The presence of these competing materials, the likely preferences of potential markets for them and the potential for increased tonnages of competing materials in future should be factored in when calculating the landbank requirements any new facility. Detailed landbank studies should be essential at the planning stage and should be conducted by experts who understand the true value of the likely outputs, the cost of necessary likely storage, transport and application and the nature of local markets in which they might be spread. Where serious difficulty exists with finding landbank or where the cost of securing landbank is high, there is the potential to separate liquid organic materials into a solid and a low dry matter liquid, both of which are often easier to store, handle and apply than the original material (see Section 4.2.3).

4.2.12 Controls in the Sewage Sludge (Use in Agriculture) Regulations (1989) (including soil pH and potentially toxic element (PTE) concentrations)

The controls in the Sludge (Use in Agriculture) Regulations, along with the rules in the Biosolids Assurance Scheme, are intended to minimise the risks associated with the application of sludge to agricultural land and to maximise the benefits. They represent a moderate control over the application of materials to land in general, although in areas where soil P status is already at or above target (which it can be in some areas surrounding sewage treatment works), the controls rightly present a major barrier to the application of phosphate-rich materials to land and provide significant protection to soil and water quality.

One application of the GIS data set that should be made in the short term is the empirical evaluation of the proposed land base that will be used for spreading of sewage sludge, based on Scottish Water's projections. The GIS data set has provided point locations, projected amounts of N, P and K along with high resolution controls that either legally (buffer strips) or due to best practice (net crop nutrient demand) limit potential spreading rates.

Whilst there have been problems in some areas of Scotland in the past, with biosolids being over-applied, Scottish Water is about to take several former PFIs back under its own control and the management of biosolids in Scotland has greatly improved. The controls associated with the regulations and the BAS are generally well known amongst the Scottish distributers of biosolids and the farmers that use them, risks are increasingly well managed and the benefits maximised.

New developments in the treatment and land application of sewage sludge since the Sludge (Use in Agriculture) Regulations (SUiAR) came into force include an increasing awareness of contaminants of emerging concern, such as microplastics, nanoparticles and pharmaceuticals including anti-microbials. The industry has also become a lot more complex during the last 30 years. For this reason, the regulators in both Scotland and England and Wales are considering changes to the way in which sludge applications to land are regulated (Environment Agency, 2019).

SEPA continue to recommend that the way in which sewage sludge is currently regulated in Scotland (through the Sludge (Use in Agriculture) Regulations (SUiAR) and the Waste Management Licensing Regulations (WMLR) should be revised and updated. It is likely that future regulatory control of sewage sludge applications to land will be in line with the Sludge Review recommendations (SEPA and Scottish Government, 2017).

4.2.13 Controls under Waste Management Licensing Exemption rules

The controls in the Waste Management Licensing Exemption rules are intended to minimise the risks associated with the application of permitted wastes to land and to ensure that the application has agricultural or ecological benefit. They rightly represent a major control to the application of materials to land in general. In areas where soil P status or PTE concentrations are above target (which they can be in some areas surrounding distilleries or other industrial facilities), the exemption rules provide particularly important protection for soils.

At a basic level, the GIS data set can now be used to evaluate individual waste exemption applications by assessing the LCA risk classifications. Any proposal to spread to high risk land (> LCA 5.2) could only be based on increased yield if it is assured that runoff will not occur and if other mitigations, such as the presence of land drains, can help remove inherent land limitations on production. The GIS data set can also be used to identify whether a clear net crop demand exists within the application locality. This is particularly relevant in areas where intensive dairy and poultry occur.

In its current form, the GIS layer can be used to identify whether the proposed spreading area is in close proximity to sensitive water bodies. Future use of the GIS may allow it to identify any direct hydraulic connectivity between proposed landbank and sensitive water bodies.

One of the authors of this report has explained to numerous farmers and contractors over the years why they cannot continue to use wastes which they have used for years under exemptions, because soil concentrations of one or more element (usually Cu or P) have become too high. In effect, the risks to the soil and wider environment would be greater than the benefit of applying the waste. However, evidence from SEPA soil testing suggests that agricultural land treated with wastes under Paragraph 7 exemptions has not suffered adverse effects more widely (Cundill *et al.*, 2012), so there is clear evidence that the rules under the exemptions to waste management licensing are providing effective protection of agricultural soils. However, there is evidence of some problems with high soil P concentrations and extremely poor quality soils on brownfield sites restored under Paragraph 8 and 9 exemptions (Crooks and Litterick, 2018).

Whilst there is good practice guidance for use of bulky organic wastes and products in agriculture, there is a lack of up to date guidance for restoring brownfield land using such materials (SNIFFER, 2010). The amount of land damaged through opencast mining in Scotland is significant, and amounts to around 3,067 ha, most of which lies in South Ayrshire, North and South Lanarkshire, West Lothian and Fife (Scottish Government, 2020). Relatively few companies are involved in restoration of this land and they plan to complete the job in little over 10 years, restoring most of the land to forestry, with small amounts of amenity and agricultural land. Given the poor quality of many past restoration schemes and the relatively short timescale to completion for the remaining schemes, the need for good guidance on best practice, which should be based on proven methodologies, is urgent.

4.2.14 Risk of pathogen transfer to food crops and water bodies

The risk of pathogen transfer to food crops and water bodies *should* be a major driver in ensuring that bulky fertilisers and soil conditioners are applied according to best practice. They should represent a barrier to the application of materials to land.

In agriculture, where manures and slurries are applied at inappropriate times of year, to crops which could be eaten raw, in poor weather or too close to water courses, the risks of pathogen transfer to food crops and water bodies are high. Several key pieces of legislation are in place to enforce good practice. These include the NVZ, CAR, Sludge [Use in Agriculture] regulations and exemptions to the Waste Management regulations. There is also excellent agricultural good practice guidance, including that on composts and digestates, which is available on the “Digestates and Composts in Agriculture” website (www.wrap.org.uk/content/digestate-and-compost-agriculture-dc-agri). Farm assurance schemes also publish rules aimed at controlling the risk of pathogen transfer to food crops. There is some evidence that faecal indicator organisms have been transferred as a result of diffuse pollution from agriculture to water bodies including bathing catchments (SEPA, 2015b). In other words, this factor is not always effective in preventing the problem.

While outside the scope of this project, the GIS data set provides the beginning of a framework for identifying a justifiable, climate-driven set of spatial rules governing where and when organic materials should not be spread to land to avoid biological risk factors.

The main guidance for forestry and brownfield land includes practical guidance on implementing the CAR regulations and compliance with the terms of waste management licence exemptions (SNIFFER, 2010). Independent monitoring of water courses flowing out of Scottish restoration sites under current restoration has shown that human pathogen numbers are generally very low, indicating that where best practice is employed, the risks of pathogens entering water courses in high numbers is low (unpublished technical work by the author of this section and her colleagues).

4.2.15 Controls on designated sites

A significant proportion of land in Scotland is covered by one or more designations, many of which are defined in law. Application of some or all types of bulky organic material are prohibited in many types of designated sites in order to maintain their character and prevent risk to the ecosystems within them (see Section 1.2.15). For this reason, controls on designated sites are a major barrier to the application of materials to land in Scotland. Landowners and land managers are usually well aware of the existence of such sites on their land and the authors are not aware of evidence of un-permitted spreading on them.

All formally recognised designated sites in Scotland have been included in the GIS data set. However, there is no systematic way of expressing any controls on land spreading as these are site specific.

The extent to which designated sites affect the application of materials to land can only be assessed on a local scale, since the proportion of designated land varies widely across Scotland.

4.2.16 Farm Quality Assurance Scheme rules and produce buyers rules

Farm QA schemes and produce buyers' rules represent a major barrier to the application of certain types of material for many farmers. Most Scottish farmers are now prohibited by their buyers from applying composts other than PAS 100 composts and waste-based digestates other than PAS 110 digestates, both of which must have also reached the SEPA end of waste positions. Application of even PAS100/PAS110 materials is frequently banned by certain buyers such as maltsters and fresh produce buyers. Whilst the science has proved that the benefits of applying PAS 100 composts and PAS 110 digestates greatly outweigh the risks, some organisations continue to ban them, stating caution, public perception and brand protection as reasons. These prohibitions do not represent law, but generally tend to be adhered to, since farmers are naturally worried that they may lose their markets if they apply prohibited materials or apply permitted materials in the wrong ways.

No spatial information on the occurrence or impact of QA schemes was identified and they are not included in the GIS data set.

There is constant dialogue between the trade bodies representing producers of certain types of organic materials (particularly composts and waste-based digestates, Renewable Energy Association Organics Recycling Group) in an attempt to secure acceptance under major assurance schemes such as QMS and SQC, however, it is not likely that the rules will be further relaxed unless the quality of typical composts (in particular) improves. Composts and digestates are excellent fertilisers and the solid types are also excellent soil conditioners. They represent a very good example of recycling and there are many good reasons for continuing to invest in the sector in order to increase the amount of organic wastes recycled in this way and to improve the quality of products made.

4.2.17 Organic farming regulations and rules

Only around 2.2% of agricultural land in Scotland is certified organic, therefore the organic farming regulations and rules represent only a minor barrier to the application of off-farm materials across Scotland as a whole. Certain types of off-farm materials are banned and permitted materials are only allowed if there is a need for them (which must be proven through soil or tissue analysis) and only at rates which provide the minimum amount of nutrients for crop production. There is no evidence that the current rules controlling or prohibiting most off-farm bulky nutrient inputs are likely to change.

Given that there was no direct or indirect method of mapping organic farms in Scotland, they were not included in the GIS dataset.

The extent to which organically farmed land is a barrier to the application of materials to land can only be assessed on a local scale, since the proportion of organic designated land varies widely across Scotland.

4.2.18 Land restoration requirements for nutrients and organic matter that do not result in over-application

Crop nutrient requirements are only one of the determinants of the amount of organic materials applied to land during restoration. Perhaps the greatest problem in most restoration sites is the extremely poor physical properties of the soil-forming materials present after the land has been re-shaped. Severe compaction, drainage problems, heavy textured soil-forming materials typically lacking in both organic matter and any sort of natural structure are common.

The organic materials most commonly used in land restoration are untreated sludges, with small amounts of off-specification composts and clean water treatment sludges also used on some sites. Whilst untreated sludges are less than ideal, because they tend to contain high P and RAN concentrations, they are the only type of material which it is financially possible to use in suitably high quantities on most restoration sites. Application rates of up to 500 dry t/ha (equivalent to between around 1,500 to 2,000 fresh t/ha) are quoted for some materials in SNIFFER (2010) and there was a general acknowledgement amongst land restoration professionals that these relatively high rates are necessary in order to kick-start soil formation by adding sufficient quantities of organic matter. The quality of restoration on some sites restored in the 1990s was however, very poor, despite the application of high rates of sludge. Much lower tonnages are currently being permitted on restoration sites, although there is a lack of clear, up to date published guidance for the companies involved on what is and what is not acceptable. One of the most recent guidance documents (SNIFFER, 2010) is often misread, misquoted and misunderstood.

4.2.19 The cost of materials (financial acceptability in different sectors)

The cost of using off-farm, non-waste materials (particularly composts and digestates) is a major barrier to their use in all sectors in Scotland. Much of the purchase price of these materials is often due to the high cost of haulage from the production facility to the landbank. Composts in particular rarely travel far from their production site and even when transported for distances as short as 25 km, the haulage cost can make up as much as 80% of the cost (to buyers) of the product. The price for food-based digestates is often heavily subsidised by the producer or digestates are sometimes supplied free of charge, because farmers would simply not be prepared to pay the full price, particularly since digestates can prove difficult to apply without risk in all but good soil and weather conditions.

Many waste materials are attractive to farmers, foresters and land restoration companies because they are free or even attract a gate fee. Land managers are able to save a considerable amount on their fertiliser bill by using some materials, such as distillery effluent or pot ale. Some farmers are tempted to apply more than they should, where they are being offered waste for free or with payment and in such cases, there is a risk of over-application of some nutrients. In land restoration, the use of waste organic materials which attract a gate fee make restorations possible and most former opencast coal sites would not be restored at all without them, given the extremely high cost of restoring land damaged in this way. Some materials which were formerly given away free are now being sold in many parts of the country (for example biosolids), but use of these materials generally compares favourably in financial terms with the use of synthetic fertiliser alternatives. It is likely that some products such as untreated sludges, low nutrient liquids and materials which are extremely odorous are likely to continue to be offered free or with financial incentives.

There is no direct GIS dataset associated with this topic but it can be evaluated indirectly by using the GIS to develop a comprehensive understanding of the available land base around point source locations.

It is impossible to generalise as to the impact of the relative costs of different types of materials on the availability of landbank for each one of them across Scotland as a whole. The materials which end up being used in a particular sector in a particular area in Scotland will depend on the tonnages and types of materials present in that area. Some areas, such as those near to distilleries, have an abundance of cheap bulky wastes, whereas other areas do not. Cheaper nutrient sources will often be chosen over more expensive ones where cheaper ones exist.

4.2.20 Carbon footprinting

At present, there is no requirement to assess the carbon footprint of waste treatment facilities, or the way in which organic materials are used in most sectors. There is increasing requirement for carbon footprinting in the farming sector, through the farm assurance schemes, although some of the programmes being used at present take little account of the carbon emissions associated with materials before they arrive at the farm. There is no GIS dataset associated with this topic.

Given the urgency of the need to mitigate the effects of climate change globally, it is possible that increasingly accurate and honest carbon accounting will be required in future, which take full account of emissions associated with all aspects of waste treatment, transport and use of wastes and products on land. If this does happen, and/or a price is to be set for carbon, then waste treatment processes and the way in which the materials being considered under this project are used on land may change in a significant way. Possible changes might include:

- A move towards a greater number of smaller waste treatment plants (particularly AD plants) which are situated closer to their waste suppliers and closer to their landbank.
- A move towards increased separation of whole digestates to produce fibre, inorganic or biorefinery products and ultra-low nutrient liquids which are discharged to sewer, river or waste water treatment.
- Increased drying/incineration of some types of organic wastes to reduce their water content and therefore the cost and carbon emissions associated with haulage, storage, spreading and the deleterious impacts (to soils) of spreading heavy materials to land. (NB; Drying may actually be very energy intensive unless renewable energy is used.).
- A change to renewable energy to power waste treatment plants.
- A ban on organic wastes to landfill (proposed in Scotland, but postponed at present), coupled with sustained efforts to improve organic waste treatment processes in order to improve the quality of composts and digestates.
- Direct subsidies or incentives to reduce or eliminate production of organic products (and therefore by-products) with a high carbon footprint.

4.3 Agricultural and non-agricultural materials that could be applied to land

Thirteen categories of organic and inorganic materials were considered in Section 2. Some of these were broad and covered many different types (e.g. animal manures and slurries) whereas others were very specific (e.g. waste ash).

For some of the materials, it was possible to get accurate, recent data on the tonnages produced in Scotland, good estimates of likely future tonnages, and excellent detail on production locations. However, this was not the case for all the materials studied. For some of the waste materials, the tonnage reported in Section 2 is subject to error and there is limited or no information on future tonnage projections or production locations. Table 4.2 summarises the annual tonnage of each material produced (most recent available data) and the percentage of the total tonnage of all materials applied to land annually. It also provides a guide as to the accuracy of the tonnage figures and any future tonnage predictions. Finally, it summarises the extent to which production locations are known for each material type. These topics are further discussed in Sections 4.3.1 to 4.3.13.

4.3.1 Animal manures and slurries

At around 11 million tonnes and representing 87% of the total tonnage of materials applied, animal manures and slurries are by far the most important type of material applied to land in Scotland. Even if livestock numbers and livestock distribution do change in future, as is likely, animal manures and slurries will undoubtedly remain more important than all the other materials added together in terms of the annual tonnage applied to land. It is therefore very important that we understand which types of material are produced where, particularly in order to be able to determine the remaining landbank for other materials in these areas and also to determine where the tonnages produced in given localities are greater than can be safely used with benefit in these localities.

The GIS data set covers this in two different ways. The first is a high resolution (2 km^2) data set showing an estimate of the amount (kg/ha) of nutrients (N, P and K) arising from livestock sources across Scotland and includes both housing and grazing periods. The data used (see Table 3.7) was derived from a model developed by (Leinonen, *et al*., 2019) and was based on the 2015 Agricultural Census data. Importantly, this is a process-based estimate that takes into consideration important factors such as the importation of nutrients into the farm system from purchased feedstuffs. A high-level review of the data set shows that in areas of intensive livestock production (dairy and poultry) there is a net surplus of nutrients compared to crop demand (Figure 7.5; Appendix A). Across most of Scotland however, there remains a net crop demand for N, P and K once the contribution from manures and slurries have been accounted. This is as expected, given that bagged fertiliser is still used widely across Scotland.

The second approach aims to provide an insight into the future direction of livestock production trends based on socio economic pressures (Table 3.11). This takes into account material generated during housing periods only. Given the uncertainty of all markets arising from changes in the UK relationship with Europe and other global markets, several scenarios have been provided covering a number of potential trading positions that the UK could take over the next 20 years. This has been restricted to a spatial assessment at the Local Authority level due to the assumption required to generate the model predictions. The future trading position will strongly influence the total amounts of livestock manures that will be generated, but importantly the direction of travel for the intensive livestock sector (dairy, poultry and pig) is highly variable across Scotland. This is important for understanding the risk of localised contributions of nutrients arising from livestock manures.

It quickly became clear when developing this and other GIS datasets that, in Scotland, the risk associated with the spreading of livestock manures and slurries to environmental and human health is occurring at local scales. This is unlike other parts of the UK and Ireland where very basic calculations at national and regional (local authority) scale indicated real concerns on the volume of nutrients being released to the environment due to livestock numbers and production methods (primarily due to the reliance on imported feedstuffs).

In Scotland, the risk from livestock manure and slurry spreading is occurring at the farm and local (inter catchment) scale. Information on the nature of these risks is easily lost if the data are scaled up to national or local authority level. Using an innovative approach, a retrospective tool was developed for this project that can assess risk at a relevant scale (2 km^2) based on the 2015 agriculture census. Unfortunately, the methods available for forecasting future livestock production trends are not sufficiently developed to be used at a local scale and this is recognised as a major limitation of the GIS data set for understating future risks associated with livestock production in Scotland.

Table 4.2. Summary of the annual tonnages of the main types of organic and inorganic materials applied to land, along with a summary of the accuracy and extent of available information on tonnages and production locations.

Category of material	Year from which data obtained	Tonnage of material applied annually	% of total tonnage applied	Accuracy of tonnage figures	Accuracy of future tonnage estimates	Extent of information on production sites	Importance of accurate info. on future tonnage estimates/production sites
Animal manures and slurries[1]	2019	11,429,935	86.6	very good	poor	very good	very important
Anaerobic digestates (not including sewage sludge)	2017	751,891	5.7	poor	poor	good[2]	very important
Drinks processing wastes (not incl. digestates)	2017	459,546	3.5	reasonable	poor	poor[2]	very important
Composts	2017	224,925	1.7	good	poor	good[2]	very important
Sewage sludges	2018/19	221,214	1.7	very good	very good	very good	very important
Pulp, paper and card wastes	2017	24,109	0.2	reasonable	poor	good[2]	important
Non-meat food wastes	2017	23,264	0.2	reasonable	poor	poor[3]	important
Food processing wastes (meat, fish)	2017	18,254	0.14	reasonable	poor	poor[3]	important
Clean water treatment sludges	2017	15,466	0.12	very good	very good	very good	important
Plant tissue wastes	2017	12,140	0.09	reasonable	poor	poor[3]	important
Waste ash	2017	10,237	0.08	reasonable	poor	poor[3]	important
Wastes from wood processing	2017	1,906	0.014	reasonable	poor	poor[3]	less important
Wastes from chemical production including gypsum	2017	1,162	0.006	reasonable	poor	poor[3]	less important
Total		**13,194,049**	100.00				

[1]Figures do not include manures deposited from grazing animals and are based on standard values for different types of animal manures and slurries (SAC, 2013).
[2]Information on the location of these production sites is good, but the tonnage of material produced at individual sites is not publicly available.
[3]The location of these sites is not known and tonnage of material produced at individual sites is not publicly available.

There is little point in determining the availability of landbank on anything other than relatively small scales in Scotland, given that most bulky materials such as manures and slurries tend not to travel far. Most animal manures are applied on the farm of origin; therefore looking at them on a farm scale is the only valid approach for most farm types. Studying manure/slurry production and landbank on a catchment or inter-catchment scale is also valuable, particularly where there is likely to be an excess of one or more nutrients being produced from livestock farms.

It is recommended that, for Scotland, the focus remains on understanding risks from manure and slurry spreading at local scales. This will entail continued development of more accurate forecasting tools that move toward farm scale rather than reliance on regional averaging.

4.3.1 Anaerobic digestates (not including sewage sludge)

Anaerobic digestates are the second most important material of those studied in terms of the tonnage applied to land annually, although the estimated tonnage of digestate (around 752,000 t) is a great deal less than the tonnage of animal manures applied to land. It is acknowledged that the most recent data (ZWS, 2019a) is out of date and that annual digestate production is likely to be higher now, since several new AD plants have been built since the data was gathered for the most recent report. The GIS dataset includes all members of the Biofertiliser Certification Scheme and some other plants, but there is no requirement for AD plants to register on any single publication or website, so it is likely that there are gaps in the GIS map of Scottish AD plants. The GIS dataset also includes a map of net energy production potential from plants. Net energy has been included as an assumptive indicator of potential nutrient output only, but we recognise that it is of limited use, since there is a limited relationship between the net energy production potential and annual tonnage of digestate produced.

Given the abundance of this type of material in tonnage terms, the lack of up to date information on the location of farm-based plants, production tonnages, typical dry matter content and nutrient values is a serious problem. Most of the digestates produced are not regulated as wastes, therefore their use is not being monitored. Little is known about the types of digestates which are being applied to land, the manner in which they are being applied, or the rates at which they are being applied. The fact that many digestates contain very high concentrations of RAN represents a clear risk to soils and the wider environment.

4.3.2 Drinks processing wastes (not including digestates)

Drinks processing wastes (from distilleries and breweries) are the third most important material of those studied in terms of the tonnage applied to land annually, with around 460,000 t being applied. Given that these materials are all wastes, and their application to land is regulated, there is more information on where they originate from and on tonnages applied than for digestates. On saying that, there is no information on the tonnage of different waste types from individual drinks production facilities. The physical and chemical properties of drinks processing wastes are likely to vary considerably depending on the process used to produce them, although there are some good average values published in SRUC (2019).

The GIS dataset includes the location and net production capacity (litres per annum) of distilleries and breweries across Scotland. Assuming that there is a relationship between distillery production capacity and the amount of waste produced, it might be possible to estimate the amount of N, P and K that may be available for land spreading but given the very limited information available on the nature of the material involved. It was not possible to include this in the GIS data set. This is far from ideal but is the best which can be done with the available information.

Given the importance of this type of material in tonnage terms, the lack of information on production locations, tonnages of materials applied to land, typical dry matter content and nutrient values is a serious problem. Although the materials concerned are wastes, the type of detailed information required to ensure that the materials are applied with maximum benefit and minimum risk is lacking. The fact that many drinks wastes contain significant proportions of readily available nutrients represents a particular risk for soils and the wider environment.

4.3.3 Composts

Composts are the fourth most important material of those studied, in terms of tonnage, with about 225,000 t being applied annually to land in Scotland. It is acknowledged that the most recent tonnage data (ZWS, 2019b, based on data from 2017) is out of date but it is not thought that the tonnage of compost being produced and applied to land is changing very much at present.

Of the compost produced, around 83% is PAS 100 product. Most of the compost produced in Scotland will be applied to land with minimal regulation (as manures and non-waste digestates are), with only waste compost being applied under exemptions (paragraphs 7 and 9). The GIS dataset includes all members of the UK Compost Certification Scheme and all other composting sites producing off-specification compost other than those operating under a waste management licence exemption. There is no requirement for composting plants to register on any single publication or website, so there could be gaps in the GIS map of Scottish compost plants, but it is thought unlikely that there will be more than one or two plants missing from the dataset.

There is no information on the tonnage being produced at each site, and given that some sites are known to produce over 40,000 t and others less than 5,000 t (based on author's experience in the industry), this data gap is important. Neither is there any data on the nutrient content or other properties of composts from different sites. Composts vary a great deal less than anaerobic digestates do, but it would be still be useful for landbank studies on particular locations to have nutrient composition data on the composts produced in that locality. Composts are useful for their nutrient content, but also because they are a particularly good source of long-lasting organic matter due to the high proportion of lignin which they contain (Bhogal *et al.*, 2018). They are a particularly useful form of organic matter for arable soils, many of which have seen serious declines in soil organic matter over the past few decades and many of whom have limited access to animal manures or other good sources of organic matter.

There is no reliable way to predict the tonnages of compost likely to be produced in the future, though we feel that they are likely to increase to some extent. There are many important drivers which suggest that we should be producing more compost, not less, but significant investment will be required from various agencies and commercial companies if the quality of PAS 100 composts is to improve to the extent that they are applied to arable land in sufficient quantities to bring genuine benefit to soils.

4.3.4 Sewage sludges

Sewage sludges are the fifth most important material of those studied, in terms of tonnage, with about 221,000 t being applied annually to land in Scotland. The data on tonnages produced and applied to land is accurate and up to date (data supplied by Scottish Water).

There is excellent information on the location of sewage treatment plants, on the tonnages produced at individual sites and on the chemical characteristics of individual products, therefore it would be easy to input the information into landbank studies at any scale. Scottish Water have produced their own predictions as to possible future tonnages up to 20 years into the future, and that too would be immediately useful for those conducting landbank studies at any scale.

The information supplied by Scottish Water has been integrated into a GIS dataset. Given the level of detail within it, the dataset would be immediately useful to those wishing to have a direct tool to understand organic nutrient availability and risk at a local level.

4.3.5 Water treatment sludge (or clean water sludge)

Clean water treatment sludges are the ninth most important material of those studied, in terms of tonnage, with around 15,455 t being applied annually to land in Scotland. This represents about 0.12% of the total tonnage of bulky materials applied. They are being included here as a separate section, along with the materials in previous sections, due to the level of accurate, up to date detail which Scottish Water have supplied about them.

There is excellent information on the location of plants producing clean water treatment sludges, on the tonnages produced at individual sites and on the chemical characteristics of individual products, therefore it would be easy to input the information into landbank studies at any scale. This information has not been put into a GIS dataset at this stage, but it could be at a later date if required under a separate project. Scottish Water have produced their own predictions as to possible future tonnages up to 20 years into the future, and that too would be immediately useful for those conducting landbank studies at any scale.

4.3.6 All other types of wastes

The total tonnage of all other types of materials considered in this project which are applied annually to land (all of which are wastes) is around 91,072t. This represents about 0.7% of all the materials applied. The wastes covered here include:

- Pulp, paper and card wastes
- Non-meat food wastes
- Meat, fish and animal origin food wastes
- Plant tissue wastes
- Waste ash

- Wastes from wood processing
- Wastes from chemical production including gypsum from various sources.

Given that these materials are all wastes, and their application to land is regulated, there is some information on where they originate from (in terms of the region) and information on tonnages applied. However, the tonnage figures are subject to error. Not all the tonnages applied for in exemption applications were actually applied to land, so reliance on these figures is likely to result in overestimates, although it was these figures which were used in this study. A study of the tonnages stated in waste returns alone is likely to result in underestimates, since data from waste returns is likely to be incomplete. The most recent available data is from 2017 and is therefore out of date.

It is not possible to determine the exact production locations of the factories concerned without studying individual exemption applications. Neither is it possible to determine the exact tonnages produced now or predicted for the future without contacting the factories directly. It is also not possible to determine the physical and chemical characteristics of the wastes applied without studying the original applications for exemptions or making broad assessments based on typical values from SRUC technical notes (SRUC, 2015, 2018).

The limited information available on these wastes has not been put into a GIS dataset at this stage, and to do so would require a considerable amount of work. Given that for most, the annual tonnages are small, their significance in terms of required landbank across Scotland is also relatively small. Each of these wastes is likely to be important in the area of land which lies within a 30 to 50 km radius around the production plant though.

The most likely way in which the value and required landbank for these wastes will be considered in future is as part of detailed, localised landbank studies. Such studies should always be conducted when planning new AD plants, distilleries or other facilities which are likely to produce large tonnages of organic materials.

4.4 Conclusions from the project

The key question which forms the whole basis of this project was: "**Is there sufficient landbank now and in the future for the safe, sustainable and beneficial use of all of the materials (as defined in this project) produced in Scotland.**" The total area of agricultural land in Scotland in classes 1, 2, 3.1, 3.2, 4.1 and 4.2 is around 2.2 million ha and the likely annual tonnage of all materials to be applied is likely to be around 13 million tonnes. If we divide the tonnage by the spreadable area, then we come up with an application rate of 6 t/ha, which does seem like a small number and might encourage the lay reader to feel that "yes" is the likely answer to the question.

Of course, answering the question with any degree of accuracy is a very great deal more complicated than that for the following reasons.

- A significant proportion of the land in Scotland is not suitable for spreading some or all types of materials considered in the project, due to legal controls, topographical, safety or logistical reasons or best practice rules. It is difficult to come up with meaningful broad figures on spreadable areas across Scotland and for that reason, the most meaningful studies on spreadable areas are those conducted on small scales, such as catchment scale, defined radii around production locations (e.g. AD plants) or farm scale.
- The need for nutrients and organic matter differs depending on many factors including soil type and soil nutrient status, topography, climate and cropping system, therefore application rates for the materials under consideration will be different (both between themselves and between sites).

- The application of some types of material are prohibited in some situations by law, not recommended in best practice guidance or avoided by farmers for other reasons, such as ensuring compliance with farm assurance scheme rules or buyer requirements.
- We can only answer the question based on the data which we have on the tonnages of organic materials produced, and for some materials, these estimates for annual tonnages are known to be inaccurate. They are likely to be increasingly inaccurate for future years, apart from for biosolids and clean water sludges, for which accurate estimates have been made by Scottish Water.
- Cost and distance from landbank affect the extent to which different types of materials are used in different areas of Scotland. It is not the case that all bulky organic and inorganic materials available in Scotland might be used readily across the whole of Scotland. For that reason, it is not appropriate to consider the landbank available across Scotland as a whole in relation to the tonnages of organic and inorganic materials produced across Scotland: the question should really be answered on much smaller scales, for example on a catchment scale, or in "economic waste/product transport areas" (such as a 30 km radius surrounding individual waste/product production facilities) or at a farm or farm co-operative scale.

4.4.1 What we have done in this project is:

- Confirmed and assessed the main (twenty) factors affecting the application of bulky organic and inorganic materials to land, including physical, land management, seasonal, climatic and economic factors and legislative controls.
- Considered the nature of the impacts and controls under twenty headings in each of four key sectors (agriculture, forestry, amenity and brownfield land) and the extent to which the controls will impact upon landbank in these sectors.
- Created GIS datasets of information and maps relating to the above factors, where possible, to help SEPA staff to assess the impact of each one geographically.
- Identified gaps in the above data which should be addressed in order to allow the assessment of landbank at a range of scales.
- Identified the main (thirteen) types of organic and inorganic wastes and products which are applied to land in Scotland as products, biosolids and wastes.
- Quantified the tonnages produced annually in Scotland of each type of material.
- Predicted future annual tonnages for each type of material where possible.
- Identified the production locations of the materials where possible.
- Created GIS datasets of information and maps relating to the location of production locations for the material types where possible, to allow SEPA staff to assess landbank for these materials.
- Identified gaps in the above data which should be addressed in order to facilitate landbank studies in Scotland at a range of scales.
- Produced a demonstration GIS dataset to show how an inter-catchment scale landbank study might be conducted.
- Answered the question "Is there sufficient landbank now and in the future for the safe, sustainable and beneficial use of all of the materials (as defined in this project) produced in Scotland." as best as we can, based on the data obtained.
- Recommended future work in the form of research and development, improved guidance, advocacy and stakeholder engagement and changes to policies and practices in order to ensure that the use of materials on land is sustainable over the next 20 years (see Objective 5).

4.4.2 Our key conclusions from the project are:

The question

- It is not possible to answer the main question which forms the basis of this project ("Is there sufficient landbank now and in the future for the safe, sustainable and beneficial use of all of the materials [defined in this project] produced in Scotland.") in simple terms. If all of the materials considered as part of this project could be spread on all parts of Scotland, then there would be sufficient landbank to which to apply them. However, the high cost of transport for bulky materials, along with the fact that much of the landbank in Scotland is affected by one or more other controls on spreading means that the availability of landbank for the materials in question differs depending on geographical area.

Factors affecting spreading

- Of the twenty main factors affecting (or potentially affecting) the application of materials to land (used for agriculture, forestry, amenity and brownfield) land capability, which is linked to topography, climate, altitude, slope and to some extent soil properties, is probably the most important. 51% (4,000,000 ha) of Scotland's land area is in LCA class 6.1 or above, which effectively means that the land will have little or no requirement for applied materials.

- The main regulatory controls on spreading are:

    - Controlled Activities (General Binding Rules), which apply to all land in Scotland.
    - NVZ Regulations (which mainly limit N loading rates from organic materials and application time for high RAN materials in NVZs).
    - Sludge (Use in Agriculture) Regulations (1989) which affect the use of sewage sludge in agriculture only.
    - Rules under exemptions from the Waste Management Licencing Regulations (2011), which affect the use of wastes in agriculture (through paragraph 7 exemptions) and brownfield, amenity and forestry (through paragraph 8 and 9 exemptions).
    - UK Organic Farming Regulations (for agricultural land that is certified organic).
    - Various pieces of legislation relating to designated sites, which cover a large part of Scotland's land area.

- The ways in which most of the other factors studied impact on spreading depend to some extent on the above legislation (and associated good practice guidance), which generally aim to reduce risk. These factors include, for example, seasonal and climatic factors, slope and topography and phosphate loading rates.

- We looked at the extent to which each of twenty factors and controls studied maximised the benefits of land applications and minimised the risks. In broad terms, we concluded that together, all of them helped significantly to maximise benefits and minimise risk, but there were some situations of concern. Given that these concerns relate both to the controls themselves and the type and tonnages of materials produced, these benefits and risks are outlined under "Benefits and Risks" in the following pages.

- In order to determine whether there is sufficient landbank in Scotland to beneficially take the likely volumes of materials in future with little or no risk, it is necessary to quantify the available landbank (taking into account the controls) at relatively small scales, since bulky materials tend not to travel far because of the high cost of haulage. Transport distances of no further than an approximate radius of 30 to 50 km from the site of production is common. There are significant gaps in the GIS datasets on landbank due to a lack of information. The suitability of the GIS dataset in terms of its ability to answer the question on landbank can be summarised as follows:

- The no-spread data set can be used to generate the current landbank that can be "legally" spread to at any scale required. The database is searchable in that the primary reason for the inclusion of any parcel of land as no-spread can be queried. At the "target scale" the spreadable land base in the buffer range (distance a material can travel) can be mapped and areas calculated.

- The main gaps that exist in the no-spread data set are:
  - controls that apply to designated areas (SSSI etc.)
  - a justifiable means of excluding land that is unsuitable for spreading based on its capacity for agricultural production (LCA).

- To provide a more accurate assessment of the "true" land base available for spreading will require a set of model parameters that define what an acceptable land base is. This will allow for the exclusion of land based on reasons other than legal controls. In addition, the current soil test data for key nutrients (P and K status) would be required to further define the spreadable land base. There may also be a few cases where concentrations of particular PTEs (e.g. Cu in areas where large historic applications of pig slurry or distillery waste have taken place, or Ni in areas where soil parent material is derived from some types of basaltic rocks) are sufficiently high to preclude spreading of some types of organic material. Such instances are likely to be rare but could be of some significance locally.

The materials considered in the project

- Animal manures and slurries are by far the most important type of material applied to land in Scotland, making up around 87% of the total tonnage of materials applied. Even if livestock numbers and distribution change, animal manures and slurries will undoubtedly remain more important than all the other materials added together in terms of the annual tonnage applied to land. The key risk is the increase of intensive livestock production systems that have a high reliance on purchased feedstuffs.

- The next most important materials under consideration (in tonnage terms) were anaerobic digestates (5.7% of the total tonnage of all materials applied annually), drinks wastes from distilleries and breweries (3.5%), composts (1.7%) and sewage sludge (1.7%). Tonnages of all the remaining wastes added together make up only around 0.9% of the total tonnage of all materials applied annually.

- For some of the materials considered, it was possible to get accurate, recent data on the tonnages produced in Scotland, good estimates of likely future tonnages, and excellent detail on production locations. However, this was not the case for all the materials studied. Data was excellent for sewage sludge and clean water sludge and the tonnage data was very good for animal manures and slurries. However, the forecasts for animal manures and slurries were subject to considerable uncertainty. Tonnage figures for composts and digestates was 3 years old. Annual tonnages may have changed since the most recent data was published and there are no forecasts for future tonnages for composts or digestates. Data on all waste materials was also 3 years old, was subject to error and no reliable forecasts could be made for future tonnages (see Section 4.3.7).

- To better determine the volumes of materials available for land spreading in Scotland in future, we need more accurate data and more robust forecasts for future tonnages. The GIS dataset which has been put together reflects the data which could be obtained under the terms of this project, but we acknowledge that with additional information and further work, it could be expanded to allow it to function effectively including all of the materials being considered in this project. As it stands, there are significant gaps in the GIS datasets on tonnages of materials and production locations due to a lack of information. The suitability of the GIS dataset in terms of its ability to answer the question on production locations and tonnages of materials can be summarised as follows:

    - Aside from the data provided by Scottish Water, the organic materials arising from point locations that have been included in this GIS data set can only be treated as indicative of a potential source of material suitable for land spreading as there is no systematic and reliable means of acquiring the tonnages and nutrient value of materials arising from the sources other than by finding the addresses of the production locations and contacting the companies directly.

    - Aside from information provided by Scottish Water on sewage and water treatment works and tonnages, the location of production facilities and associated data that was included in the dataset was acquired from publicly-available sources that were created and made public for differing reasons. These cannot be assumed to be completely accurate. Accurately understanding the amount of plant nutrient arising from point source waste streams will require a reporting system that states probable or actual annual output tonnages of waste, along with at least a basic description or ideally an accurate analysis of the nutrient content of the waste.

    - It is crucial that any future industry data on volumes and nutrient values of waste arising and intended for land spreading be attributed to a fixed location and have sufficient detail to reasonably predict the amounts of N, P and K that are being made available for land spreading on an annual basis.

- Scotland has a continuing overall net crop demand for N, P and K once livestock manures and slurries have been accounted for (see section 2.2 for full discussion). For P, however, the spatial distribution of this net demand is largely restricted to the eastern half of the country. There are also pressure points in and around intensive agricultural areas and areas where large amounts of organic materials, such as digestate are produced, but the geospatial evidence indicates that land spreading of current and projected organic materials arising from non-farm sources can be done sustainably *assuming there are no socio economic controls.*

  An obvious socio economic pressure for Scotland is that the highest net crop demand for nutrients (N and P) occurs in geographically distinct areas associated with high yielding arable production in the east of the country. The specific geospatial points at which some organic fertilisers, such as sewage sludge, digestate and composts are arising do not always correspond, geospatially, with this demand.

- Historic and economic factors have meant that many fixed point sources of organic fertilisers in Scotland, such as distillery by-products, digestates, livestock manures from intensive production (poultry and dairy) are located in areas where local crop nutrient demand is limited or fixed which will increase transportation costs if they are to be land spread without posing a long term environmental concern.

- Financial (transport costs) and other social pressures (attitudes to sewage sludge for example) are creating concerns at the local and regional scale and the evidence generated from this study should be applied at a catchment and inter-catchment scale to understand and mitigate these current and emerging issues.

Benefits and risks

- There is good information on the chemical and physical properties of most of the materials under consideration, particularly for the six materials which are applied to land in greatest quantities and for clean water sludge. For that reason, the benefits and risks of applying these materials are generally well understood, although there is an awareness of the potential for contaminants of emerging concern to raise questions over the suitability of some materials for land application in future (particularly with wastes and biosolids, but also with other materials).

- At present, the greatest known risks thought to be associated with use of the materials under consideration on land relate to their P, RAN and potentially toxic element content.
  - There is evidence that both the Sludge (Use in Agriculture) Regulations (1989) and the rules under exemptions to Waste Management Licencing do a good job in managing PTE concentrations in soils to which biosolids and wastes have been applied in most situations.
  - There is evidence of excessively high P concentrations in some agricultural and brownfield soils, which will have resulted from excessive applications (probably mainly of sewage sludge, poultry and sometimes pig manures).
  - There is evidence of N losses to water (primarily through nitrate leaching) and to air (primarily as ammonia and nitrous oxide emissions).
  - In comparison to wastes and sewage sludges, there are few controls over manures, slurries and anaerobic digestates and composts which achieve end of waste. These are often applied repeatedly and there are no checks and balances in place to ensure that soil PTE concentrations are becoming excessively high, pH is being adversely affected or that nutrients are being over-applied, with resulting problems for soils and surrounding watercourses and water bodies.

- Given the damaging effects which excessive concentrations of both P and N can have in aquatic ecosystems (and to air quality), it is essential that organic materials are applied to land in such a way that little or no N or P enters watercourses as a result of these activities. Similarly, applications should be managed to limit leaching of nitrate to groundwater. Whilst legislation exists to help prevent water pollution from these and other elements, this project has highlighted some potential concerns over water quality both now and in the future. These are as follows:
  - It has not been possible to fully assess the degree of risk across Scotland with this project. The process of creating the geospatial data set has highlighted the ineffectiveness of using political boundaries as a tool to manage and understand land spreading risks. The real risks to water, land and human health are at the inter-catchment scale and evidence of risk is lost when information is transformed to conform with political boundaries.
  - The only way to effectively assess the potential for risks from the spreading of organic and inorganic materials is to develop GIS datasets which work at the inter-catchment scale. Such datasets should include all spreadable land, should take into account all types of controls and factors affecting the potential for spreading. They should assess the requirement for nutrients (particularly N and P), bearing in mind the availability of animal manures and slurries in the inter-catchment, along with all other materials (such as digestate, distillery effluent and sewage sludge).

  - A particular concern for the future is the possible centralisation and intensification of dairy and poultry (and possibly also pig) production as well as waste water treatment facilities. These could create nutrient hotspots which should be monitored and managed with great care, taking into account the significant ammonia emissions (and local deposition) as well as the materials deliberately applied to land.
  - Another concern is the importation (at a national scale) and movement (at a regional scale) of animal feedstuffs. It may be possible to monitor movements of animal feed, since manures from intensively produced animals is more nutrient-rich. By monitoring movements of animal feedstuffs, it may be possible to predict potential pollution "hotspots".
  - Subsidies have distorted the AD sector to the extent that plants often occur in clusters, resulting in shortages of cost-effective landbank in their vicinity. Also, many AD plants, distilleries and some other factories have insufficient storage for their liquid wastes and digestates. The result of both of these problems is that there is considerable anecdotal evidence that digestates are often applied at the wrong time of year, using old fashioned splash plate spreaders, in inappropriate weather and soil conditions and at excessively high application rates. Much of the storage where it does exist is in uncovered outdoor lagoons, where the potential for ammonia losses is high. As it stands, AD poses significant pollution risks, which should be addressed at both local and national scales.
  - Paragraph 7 exemptions, whilst providing important controls over the amounts of materials applied in a year, do not control the time of year at which the material will be spread.

- Based on the limits of this study the total amount of animal feedstuffs (concentrates) imported into farming systems from both within and outside the UK is the single most significant variable giving rise to systemic risks to water quality from livestock manures and slurries. SEPA consider that manure management is the most significant factor giving rise to risks to water risks (M Aitken, pers. comm.). Very few closed or low input farming systems within Scotland are capable of producing plant nutrients from livestock sources that exceed the crop requirements of the farm system itself. It is recommended that the annual use of animal feedstuffs be highlighted as a key diffuse pollution indicator in all future work to improve the spatial understanding of risks to water quality arising from livestock production.

  - Clean water sludge has been applied to brownfield land for many years, but its impact on soil properties has not been studied in depth. Given Scottish Water's interest in using it in agriculture rather than brownfield, there is a need to know more about how to use it to best effect. A project to evaluate the physical and chemical properties of clean water sludges from two different treatment works and to determine the beneficial properties and potential risks from applying them to agricultural land is now underway and is being funded by Scottish Water.

  - All future formal processes that detail the generation of, and eventual land spreading of, organic fertilisers should be required to have a spatial (GIS) component. This would include all waste management licence exemptions and applications for planning permission (including for AD plants, composting facilities, sewage treatment works and intensive animal production facilities). GIS has now developed to the point that its use is often the most cost-effective means of creating information that is already required for such applications (for example RAMS maps). In the worst case, the cost associated with the creation of GIS data is now wholly predictable and therefore can be included within costs associated with the sustainable end use for organic materials. Deliberate changes and incentives within the waste market which have been supported by or implemented by Scottish Government, SEPA and Zero Waste Scotland have resulted in land spreading becoming a cost-effective and reliable outlet for organic material. It is now time for some of the profits made by those producing organic products and wastes to be invested in providing meaningful and accurate data to ensure they are being used sustainably, with benefit and in such a way that harm to the environment and human health is minimised.

- At present, there is no requirement to assess the carbon footprint of waste treatment facilities, or the way in which organic materials are used in most sectors. Given the urgency of the need to mitigate the effects of climate change globally, it is possible that increasingly accurate and honest carbon accounting will be required in future, which take full account of emissions associated with all aspects of waste treatment, transport and use of wastes and products on land. If this does happen, and/or a price is to be set for carbon, then waste treatment processes and the way in which the materials being considered under this project are used on land may change in a significant way.

A series of recommendations have been derived from work conducted in the project. These are set out in Section 5.

5 Recommendations on changes required to policies and practices to ensure the use of materials on land is sustainable over the next 20 years

This section presents recommendations aimed towards ensuring that the use of materials on land is sustainable, beneficial, and safe over the next 20 years. It includes recommendations for research, development and assessment work, policy changes, improved guidance documentation, advocacy and stakeholder engagement and knowledge exchange (highlighted in italicised blue text). It is understood that SEPA would not necessarily fund or instigate all of the recommendations but would continue to work with partners and industry to achieve the goals outlined below.

5.1 Recommendations for research, development and assessment

Information and tools are lacking in some key areas if we are to ensure that materials are used safely and to best effect across Scotland in future. Key projects and areas for research, development and information gathering include the following:

- *Determine exactly where all wastes and products suitable for application to land are produced in Scotland, the tonnages produced at each site and the physical and chemical characteristics of materials produced at each site. Whilst this is useful for the wastes produced in lower tonnages (< 15,000 t/annum for example) it is surely essential for materials such as distillery effluents and digestates, for which information is currently inaccurate and out of date (as described for individual waste types in Section 2). Information gained from this study will allow production of accurate, fully functional GIS datasets which can be used to conduct landbank studies at a range of scales.*

- *Continue to develop the GIS dataset, so that it can function at inter-catchment scale (and above) for the whole of Scotland. Production of this dataset will involve securing new data which is not yet in the public domain. This dataset should include map layers that represent all "mappable" controls, outlets, tonnages and nutrient content of materials as defined in this project, that is, layers should be included which cover at least:*
    - *Land capability.*
    - *Seasonal and climatic factors.*
    - *Slope.*
    - *Proximity to water bodies/water courses.*
    - *Crop nutrient requirements.*
    - *Leaching risk from soils.*
    - *Soil P sorption capacity.*
    - *NVZs.*
    - *Designated sites.*
    - *Availability of nutrients from livestock manures and slurries (across inter-catchments rather than in politically defined areas).*
    - *The location and typical market area (radius) for each plant producing materials which could be available for spreading.*
    - *The amount of N, P and K available for spreading from each plant identified above.*

- The Scottish Vacant and Derelict Land Survey provides a summary of the total areas of vacant and derelict land in Scotland, but it does not provide details of the names, owners, exact location or area of sites. (Scottish Government, 2020). Neither does it include details of sites which will require restoration in future (e.g. quarries and active landfill sites).

- *Develop a publicly available database of brownfield land for Scotland, ideally with maps, area (in ha) and current ownership. A useful addition to this might include active quarries, opencast mineral sites and landfill sites).*

- *Support the development of an automated Risk Assessment for Manure and Slurry (RAMS) system which should work with all liquid and solid organic materials, not just agricultural manures and slurries. This has been developed for parts of Scotland, but making it available to all farmers, land managers and contractors in Scotland is now possible. If completed, this would help deliver effective best practice and regulatory compliance.*

- *Update Scotland's Land Capability maps for agriculture and forestry based on current climate predictions and ensure that they can be integrated into the recommended GIS dataset (see above). It is understood that this work is already underway at James Hutton Institute.*

- *Following discussions with SEPA, studies (funded by Scottish Water) have already commenced to further understand the potential benefits, risks and suitability of spreading clean water sludge on agricultural land. This project is due to finish in 2020.*

- *Conduct a project to identify examples of land to which manures, slurries, PAS 100 composts and PAS 110 digestates have been repeatedly applied with reasonable records of such applications. Test the soils for parameters of concern (in particular soil pH, soil extractable P, PTE concentrations, microplastics, some persistent organic contaminants and (in the case of composts, physical contaminants) and determine whether there might be a case for future regulation of such materials in order to protect soils.*

- *Continue the work to identify possible contaminants of emerging concern and to evaluate the impact of applying materials to land which contain them. It is understood that important work on this topic is underway in several countries across the world and this should be considered.*

- *Develop (and/or refine existing) full life cycle carbon footprinting tools to evaluate the carbon footprint of individual farms and individual factories which produce wastes and products which could be applied to land. Given the importance of climate change mitigation for all countries, these should take into account **all** sources of carbon dioxide equivalent emissions, including those from haulage and those associated with all imported materials including chemicals, machinery, equipment and fertilisers. In future, we should only be allowing new facilities to be built if they are genuinely "carbon neutral" and we should be working towards making all operational farms, factories and waste management facilities genuinely "carbon neutral" too.*

- *Conduct a project to determine in detail how digestates and distillery wastes/by-products are being stored, transported and used in Scotland. There is anecdotal evidence of bad practice on a number of counts, which is likely to be leading to over-*

application of nutrients and may also be leading to contamination of soil, pollution of water bodies, water courses, maritime environments and the air (ammonia) as well as affecting climate (emissions of nitrous oxide – a powerful greenhouse gas). This project will provide evidence to help factory/plant managers improve their working practices in order to minimise pollution, conserve nutrient resources and cut their carbon footprint. Further legislation may be required to force such factory/plant managers to adopt best practice.

- *Conduct a project to determine the amount of manures and slurries being produced from IPPC-permitted intensive livestock operations and look at how these materials are being stored, transported and used in Scotland. There is the potential for over-application of nutrients locally and for air pollution (associated with emissions of ammonia) and impacts on climate (nitrous oxide emissions). This project will provide evidence to help farmers improve their working practices in order to minimise pollution, conserve nutrient resources and cut their carbon footprint.*

- The problems caused by production of large tonnages of liquids from the AD and distillery sectors (in particular) are considerable in some geographical areas. We do not really understand the financial value and environmental impact of nutrients lost through discharge of some of these liquids to rivers, sewers and sea. We have not calculated the full financial or environmental cost from N lost through inappropriate (and even appropriate!) applications of these materials and we have not calculated the true haulage (or carbon) costs for transport of the liquids to landbank or elsewhere. Whilst many large plants and several commercial companies are now working on methods to de-water and use digestates for purposes other than land application of the liquid, we recommend:

    - *Conducting work to better understand the full financial and carbon costs of current and potential future practices.*

5.2 Recommendations for policy changes

Some of the above work and other activities required to allow sustainable, beneficial and safe use of materials on land in a changing world may quickly run into difficulties without policy changes. All of those proposed below aim to help us better understand the nature of risks and minimise them, whilst maximising the benefits associated with land spreading materials. Recommendations for policy changes include the following:

- Managers of AD plants, distilleries, composting sites and waste treatment facilities are often reluctant to talk to researchers, consultants (and possibly regulators?) about their production practices and output tonnages or to provide test data on physical and chemical properties of their outputs. There is currently no requirement for them to comply with requests for such information, with the result that response rates for even the most basic questions asked in organics recycling surveys can be as low as 70%. Whilst this is a good response rate for a survey of this type, it is sufficiently low that it is impossible to gain a good grasp of the nature of the sector. So:

    - *Put measures in place to make it compulsory for all product manufacturers and waste producers (including third party waste contractors) to submit to SEPA annual returns of the tonnages of all materials produced at each location (which could potentially be applied to land) and their eventual fate (for example, did these materials go to a third party or direct for use as an AD feedstock, animal feed, biomass or land application?). Regular waste analysis* *for key parameters would be needed as part of this requirement (see below). The objective is to have accurate information on exactly how much of each material of each type is taken from where (fixed geospatial point from which material is then taken for land spreading). Information on temporary on-farm storage should not be required.*

- *All product manufacturers and waste producers should also submit at least two sets of test data (one per 6-month period) for all "market-ready" materials which could potentially go to land. This information already exists in most cases, but it is not available to SEPA. These results will be useful for SEPA when trying to assess the total amount of phosphate (or other nutrients or PTEs) being produced in particular areas, for those conducting landbank studies or preparing GIS datasets or any company or individual wishing to use the material on land. The test suite would depend on the material concerned, but it should at least include the following:*
    - *Dry matter content and fresh bulk density.*
    - *Electrical conductivity, pH.*
    - *Organic matter content (LOI), total C and C:N ratio.*
    - *Total N (Kjeldahl OR Dumas method).*
    - *Available N (ammonium and nitrate).*
    - *Total P, K, Mg, S, Ca, Na (aqua regia digest.)*
    - *Total PTEs (Cu, Cr, Cd, Hg, Zn, Pb, Ni, Mo, As, Se).*
    - *Total fluoride.*
    - *Neutralising value.*
    - *Physical contaminants (glass, plastic and metal fragments - test required for waste-based composts and digestates only*).

- *All future formal processes that detail the generation of, and eventual land spreading of, organic fertilisers should be required to have a spatial (GIS) component. This would include all waste management licence exemptions and applications for planning permission (including for AD plants, composting facilities, sewage treatment works and intensive animal production facilities).*

- *Consider the benefits of enhancing the Controlled Activities Regulations and General Binding Rules to include limits on N applications and the requirement for closed periods similar to those in the NVZ Regulations. Both these measures represent sound economic sense for farmers, as well as environmental sense. The greatest risks (outside existing NVZs) are likely to be in areas surrounding distilleries, large AD plants and any other AD plants that have insufficient digestate storage.*

- Following on from the proposed project to determine the impact of repeated applications of manures, slurries, PAS 100 composts and PAS 110 digestates on soils:

    - *Consider whether there might be a case to develop regulation of such materials in order to protect soils. This is likely to involve the development of quality standards for soils, which may differ depending on factors such as land capability class, soil texture, land use (including crop rotation, forestry type etc.). Such quality standards would include (at least), soil pH, maximum soil PTE concentrations and soil P status in relation to target for the land use/crops concerned.*

- The fact that manures, slurries and anaerobic digestates and composts which achieve end of waste are largely unregulated when applied to land means that we have inadequate specific information on whether soils and surrounding watercourses are at risk.

- *Consider regulations on maximum application rates and soil concentrations for PTE and P, beyond which no further applications are permitted.*

- Given the significant changes in the sewage sludge sector since the Sludge (Use in Agriculture) Regulations (SUiAR) came into force in 1989, it is important that SEPA continue to recommend that:

    - *The way in which sewage sludge is currently regulated in Scotland (through the Sludge (Use in Agriculture) Regulations (SUiAR) and the Waste Management Licensing Regulations (WMLR)) is revised and updated in line with the Sludge Review recommendations (SEPA and Scottish Government, 2017).*

- Carbon footprinting is directly correlated to efficient nutrient use on a number of fronts, not least that when fertiliser (particularly in the form of P and N) is wasted through being over-applied or applied in inappropriate conditions (thus resulting in losses), then fertiliser must be imported to make up for that loss. Importation of P (a finite resource) and N is expensive in financial, energy and carbon terms and both should be conserved at all costs.

    - *Make full life cycle carbon footprinting compulsory for all manufacturing and waste recycling businesses as well as all farms, with priority for this measure being levelled at renewable energy facilities. All of these operations must aim towards being genuinely "zero carbon" for all aspects of their operations including transport of wastes or raw materials to the premises, manufacturing (including the use of all imported fuels, waste products, products, equipment and machinery), transport and application of materials to land.*

- The quality of restoration on some of the earlier restored brownfield sites in Scotland is abysmal. Many supposedly restored sites are semi-derelict and some of those which have been restored are in poor condition, with dead or dying trees in forestry sites or abundant rushes and rank grasses in sites purportedly restored for agricultural grazing. Recommendations as to how to address this problem for past, current and future sites would form a substantial project in themselves! However, in addition to recommendations for new and improved guidance documentation (see following section) the following is recommended in brief:

    - *Develop new legislation for minimum standards for restoration (in terms of soil quality [in particular compaction relief (ripping and cultivations), soil P and K status, organic matter content and PTE concentrations]), post-restoration management and monitoring, drainage system and water quality.*

    - *Make it a (compulsory) planning requirement that all developers should conduct a detailed landbank assessment for proposed AD plants, distilleries, composting plants, intensive pig, poultry and dairy farms and all other facilities making products or wastes that might be applied to land. Define standards for the type of study which is required and for the level of expertise required to produce it. If the landbank assessment for an individual plant highlights a lack of appropriate local landbank, then the plant in question should not be permitted, or it should be required to find carbon neutral ways in which the landbank shortage can be addressed.*

5.3 Recommendations for new and improved guidance documentation

- There is a lack of tools and guidance to allow carbon footprinting for manufacturing and waste treatment facilities that take into account all aspects of the production cycle from start to finish and including all imports.

    - *Produce guidance on whole life cycle analysis carbon footprinting for plants producing materials which might be applied to land.*

- There is a lack of clear, simple guidance for land restoration companies and contractors on best practice in land restoration. Existing guidance is out of date in relation to the standards and practice currently being requested by SEPA. It is understood that Forestry and Land Scotland are in the latter stages of producing a short guidance document on restoration of former opencast land for forestry, but this is very much for forestry purposes and other guidance is required, ideally stating SEPA's key requirements for working practices and for the characteristics of restored soils. Specialists within the land restoration sector could be encouraged to collaborate fully with SEPA in order to:

    - *Produce guidance on how to restore brownfield soils for the purposes of agriculture, forestry or amenity.*

- There is excellent good practice guidance to assist land managers, particularly in agriculture and forestry and particularly relating to the use of animal manures, composts and digestates. However, published good practice guidance aimed at helping land managers use materials such as biosolids and the more unusual wastes, such as gypsum, mushroom compost and distillery wastes is lacking. Specialist consultancy companies could be encouraged to:

    - *Produce simple, clear information sheets on how best to use biosolids and the more unusual wastes such as gypsum, mushroom composts and distillery wastes.*

- There is evidence that simple, clear information sheets can help companies market their products and wastes (those suitable for land application) effectively, but most have no idea how to produce them. This is an opportunity for specialist consultants, but SEPA might consider recommending such an approach for companies which are failing to manage their wastes and products well.

    - *Produce simple, clear information sheets on the benefits, financial and other values and safe application methods for wastes and products*

5.4 Recommendations for advocacy and stakeholder engagement

- There is still a culture of "waste disposal" amongst many operators of distilleries paper mills, abattoirs, food production facilities and even AD plants and composting sites. There is an increasing need for experts in waste management and materials to land to engage with companies in order to help them make the best of their wastes and resources. There are environmental, marketing, public relations and financial benefits for companies which consider the best environmental options for wastes produced at every stage of the production process. There may be opportunities for SEPA to help direct this work, most of which would need to be tackled by specialist consultants. These specialist consultants should:

- *Engage with operators individually, at trade conferences or through short communications (by letter) to inform them of the advantages of considering:*
  - *Full carbon footprinting of their operations*
  - *Assessment of the opportunities for re-purposing some of their wastes, by-products and products for environmental and/or financial gain. This is likely to involve increased laboratory and field testing and assessment of these materials.*

5.5 Recommendations for knowledge exchange

- There is excellent published guidance available for farmers and land managers on how to use high RAN liquids (and to a lesser extent other materials) safely and to best effect, but the authors are still aware of a lack of understanding amongst some Scottish farmers about how best to use them. There is an ongoing need for locally-based knowledge exchange events, so:
  - *Continue to ensure that farmers and land managers understand how to use organic materials (particularly high RAN liquids) safely and to best effect by running workshops, seminars and field days. Pay particular attention in each case to materials available locally and tailor the events to locally prevalent crop rotations and land uses. Invite managers of local AD plants, composting plants, distilleries and waste treatment plants and encourage sharing of information.*
- There is a growing interest in soils amongst farmers and farm managers, with record numbers attending conferences, farm walks and taking part in farmer-led studies on the subject. However, the authors are aware that there is a lack of knowledge about the influence of soil type and soil quality on the best practice in applying bulky organic fertilisers. There is also a lack of knowledge as to how to choose and use such fertilisers in order to maintain and improve the health of specific soils. There is an ongoing need for locally based knowledge exchange events on this topic, so:
  - *Prioritise continued events aimed at helping farmers and land managers understand how to use bulky organic fertilisers to best effect in order to:*
    - *Save money on synthetic fertilisers by making the best of their own manures and slurries and using locally available materials.*
    - *Improve their soils.*
    - *Minimise the risks by applying the materials at appropriate times of year, at appropriate rates and in appropriate ways.*
- There is a serious lack of understanding about soils and nutrients amongst contractors and land restoration company personnel, some of whom are focussed simply on applying as much organic waste to land as they can in order to maximise revenue.
  - *Consider opportunities to address this lack of knowledge through conference presentations at appropriate brownfield conferences. The message could be enhanced by talking about the opportunities to maximise the financial value of effectively restored land (carrot) and potential future regulation (stick).*
  - *Consider supporting an accreditation scheme for operators applying all organic (and possibly inorganic) materials to land for agricultural benefit. Such a scheme (or schemes should apply to forestry, brownfield land and amenity land, not just agriculture).*

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7 Appendices

Appendix A – Illustrations showing examples of the maps created via the GIS datasets

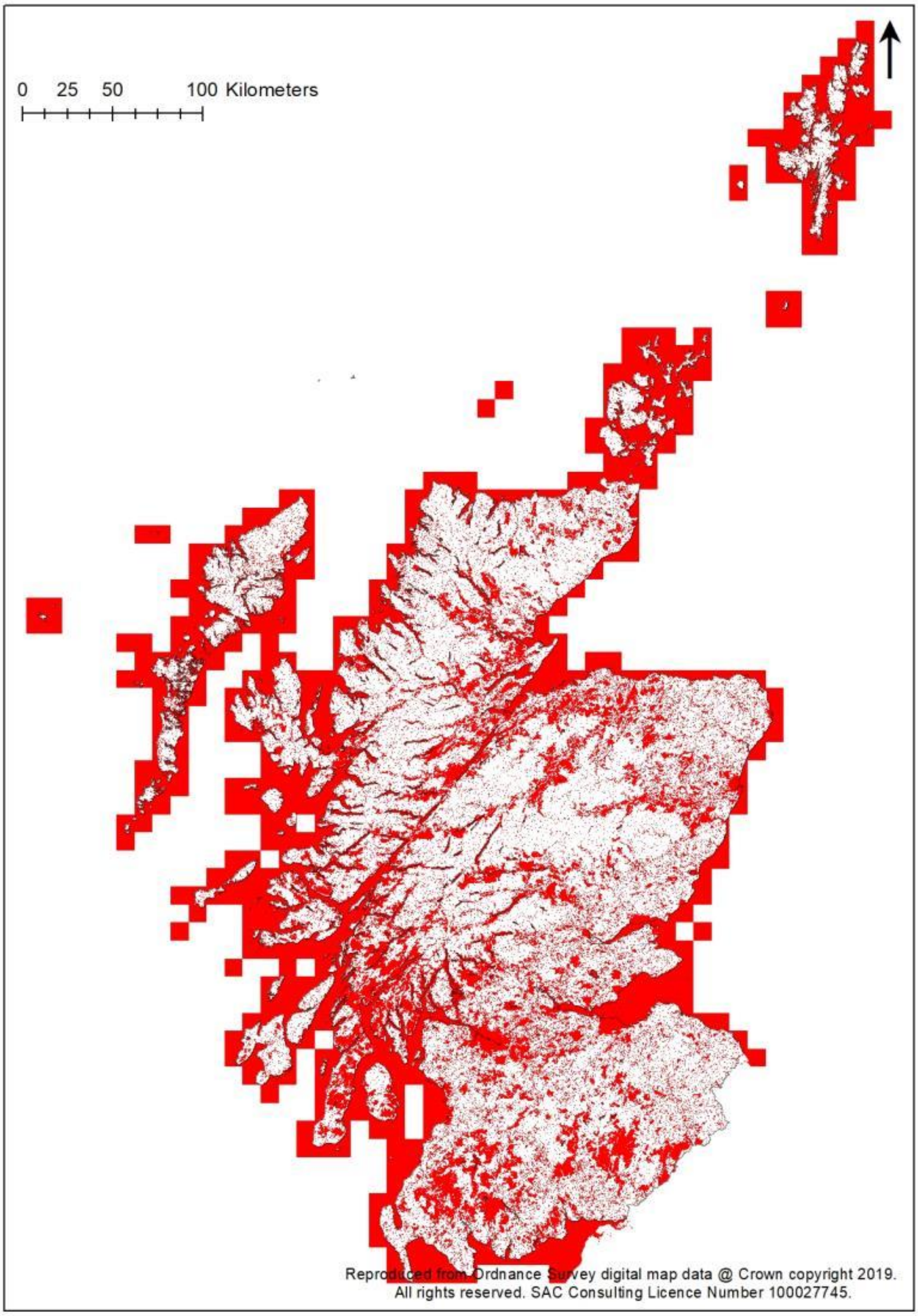

Figure 7.1. National map (1:2,500,000) of areas that have been classed as no-spread.

This data set represented in Figure 7.1 shows all area of Scotland where there are legislative controls over the spreading of organic materials to land.

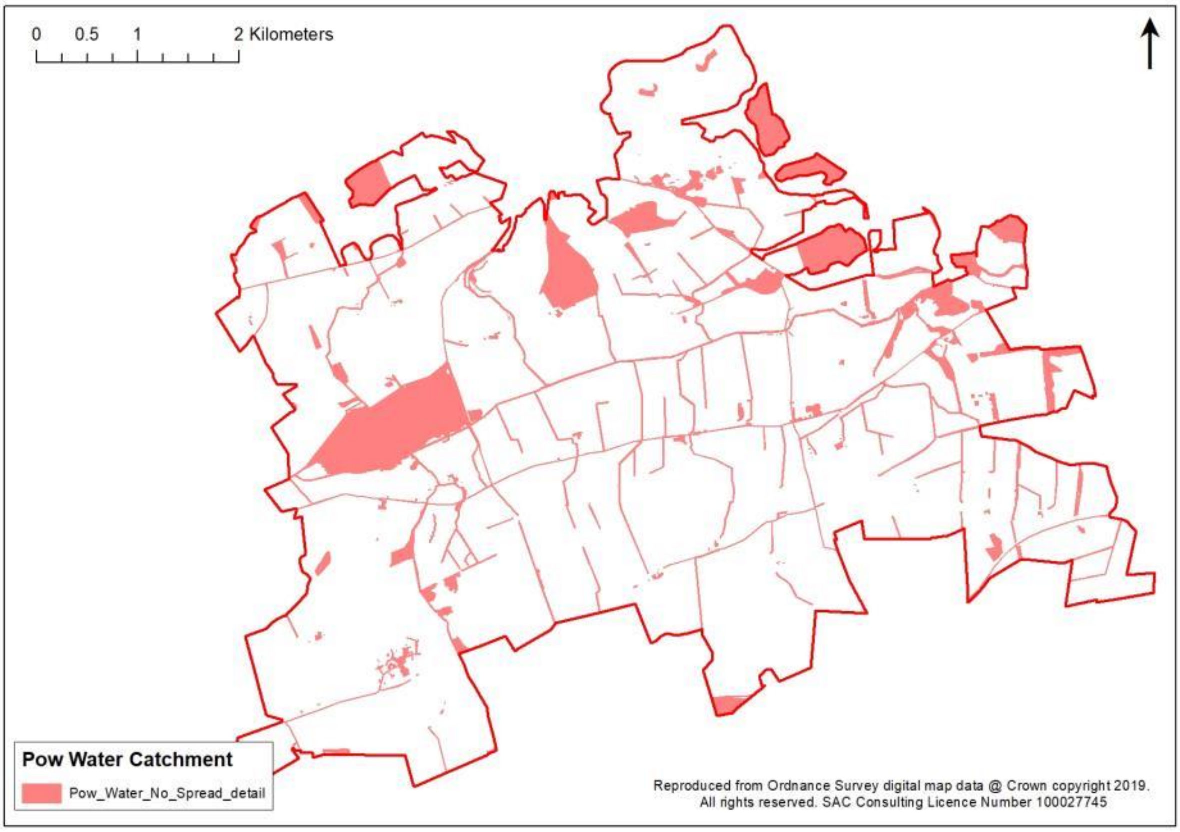

Figure 7.2. Example of the no-spread data set for the Pow Water catchment.

Excluded areas include all water courses, required buffer strips, woodland and urban areas.

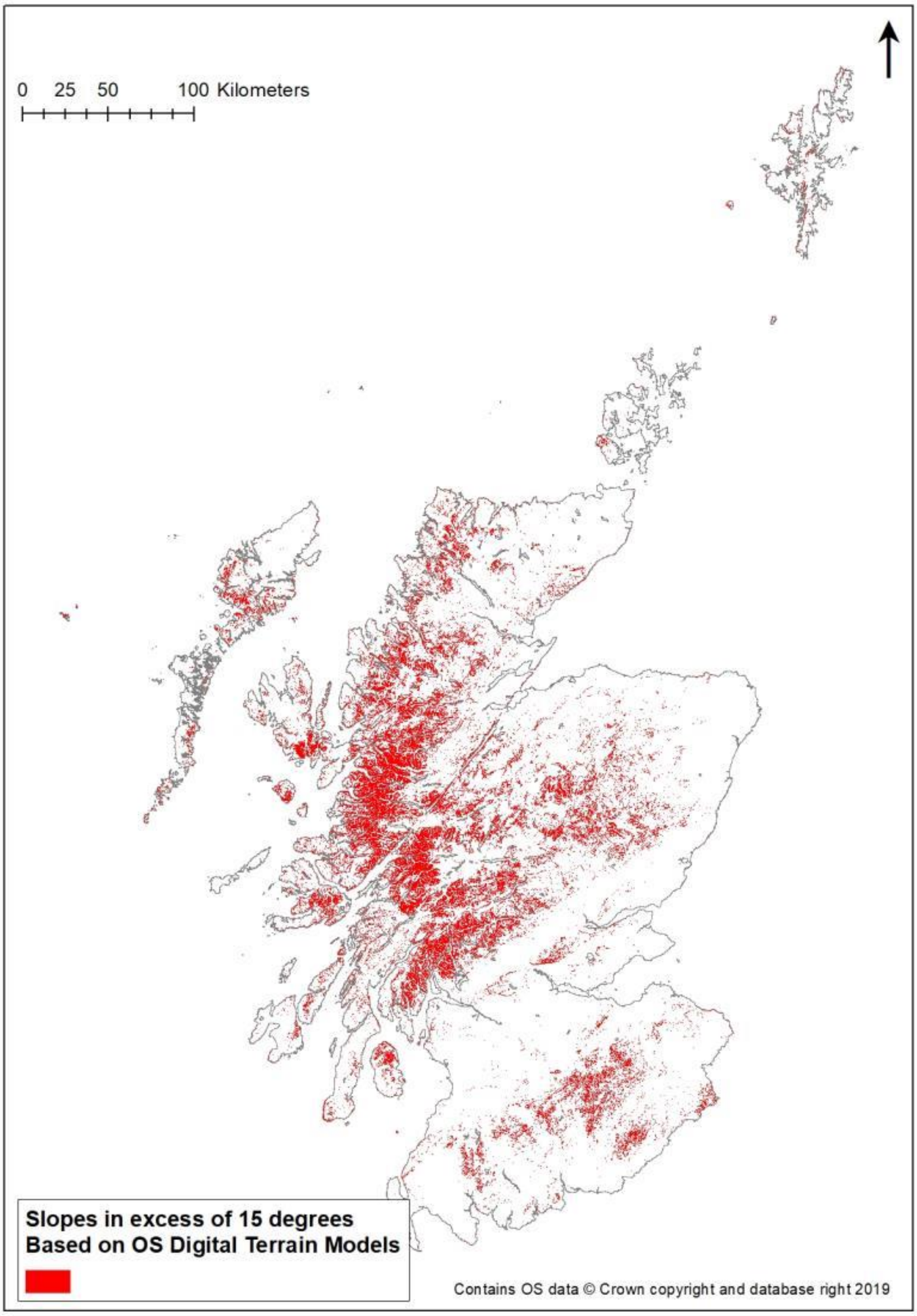

Figure 7.3. Areas with slopes in excess of 15ºbased on an OS 50 m Digital Terrain Model.

This data set represented in Figure 7.3 shows all area of Scotland that have a slope > 15º and represent areas where slope should be a consideration when spreading organic materials to agricultural land.

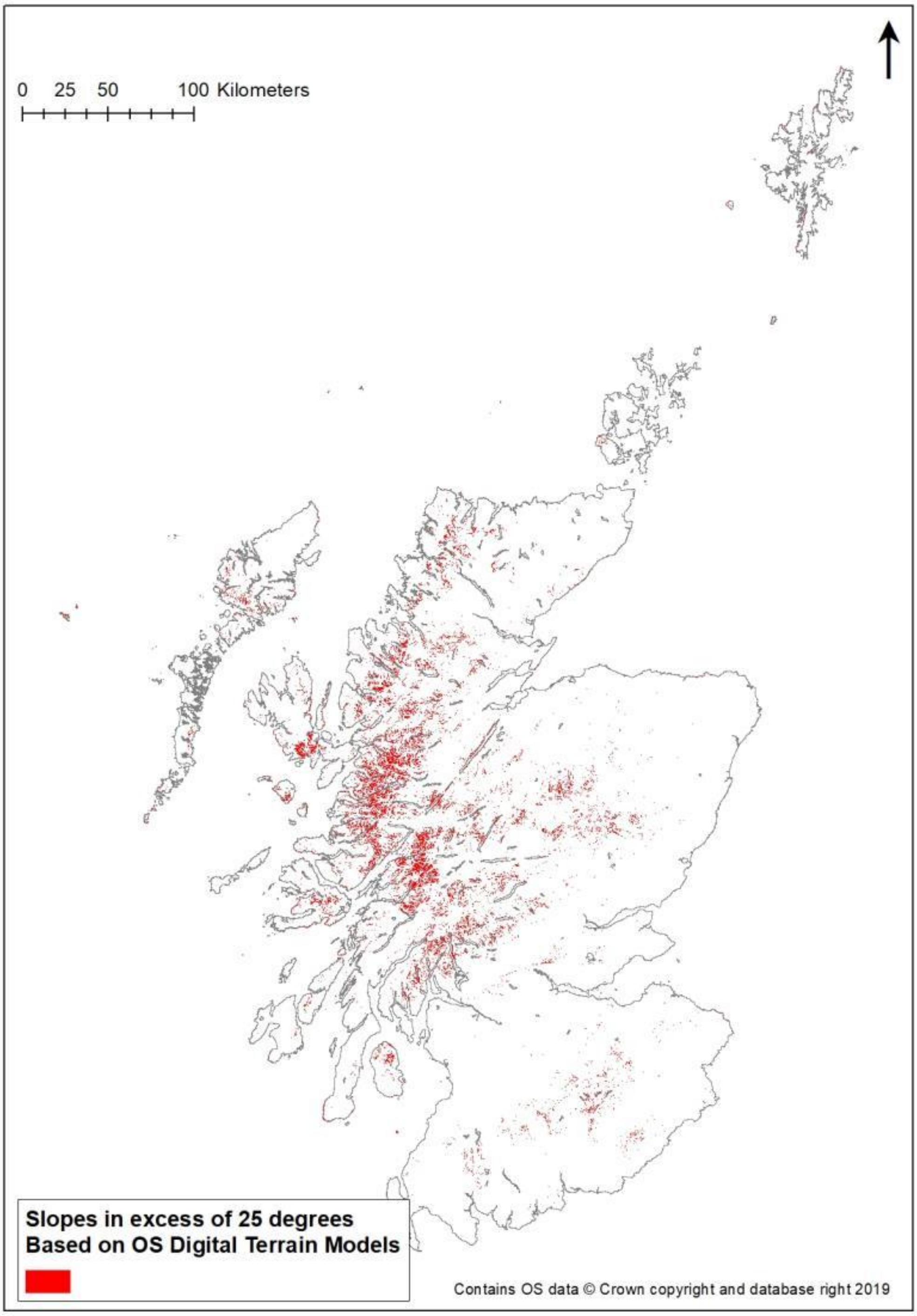

Figure 7.4. Areas with slopes in excess of 25º based on an OS 50 m Digital Terrain Model.

This data set represented in Figure 7.4 shows all area of Scotland that have a slope > 25º and represent areas where slope should be a consideration when spreading organic materials to agricultural land and forestry.

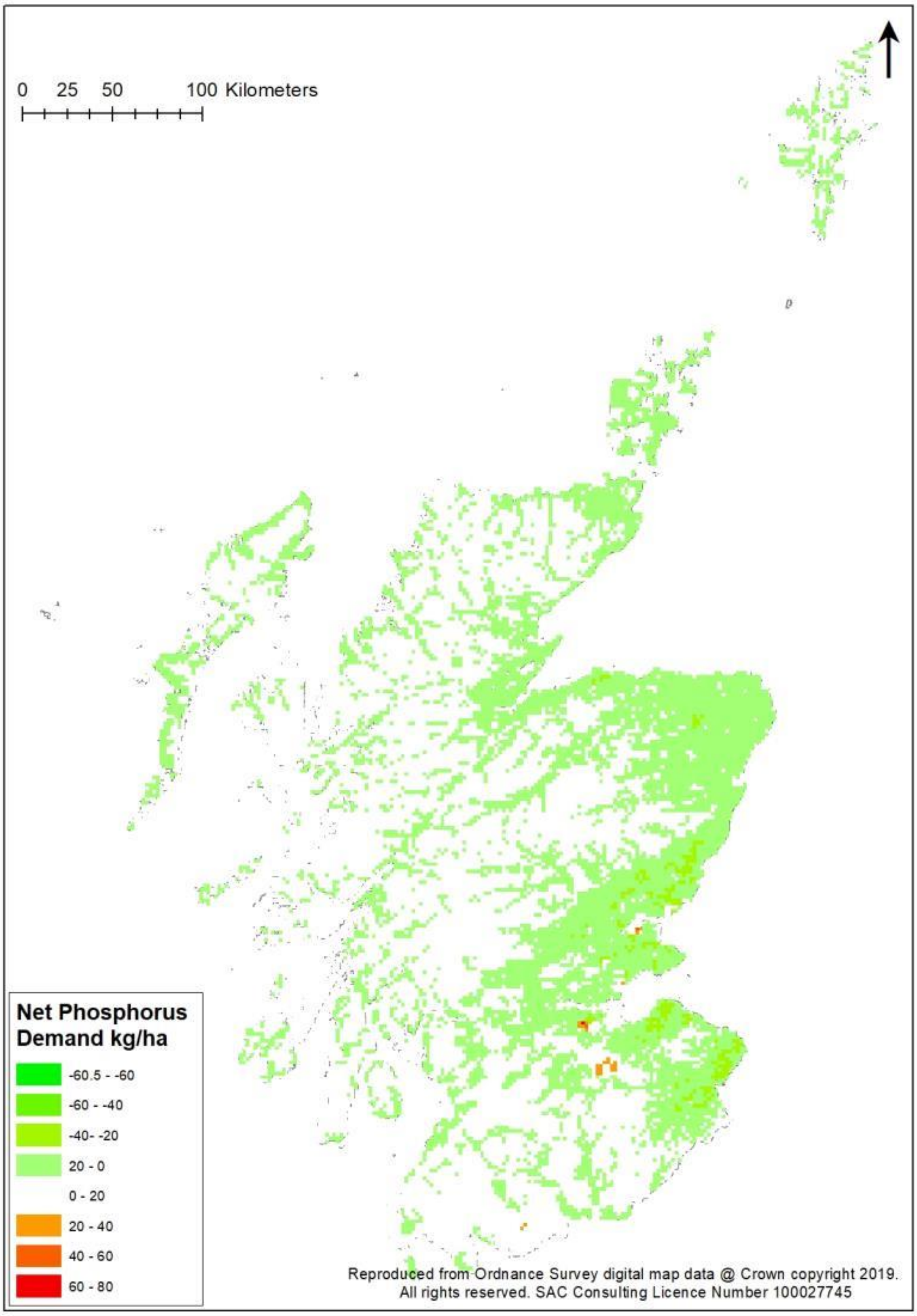

Figure 7.5. Net P demand after the fertiliser value of animal livestock manure and slurry has been accounted for.

Negative numbers indicate a net demand indicating the need or opportunity to apply bagged fertiliser and/or import organic fertilisers to meet crop requirements. Positive numbers indicate a surplus due to intensive livestock production and the supply of nutrients are higher than crop need. See section 3.3.1 for full description of data set.

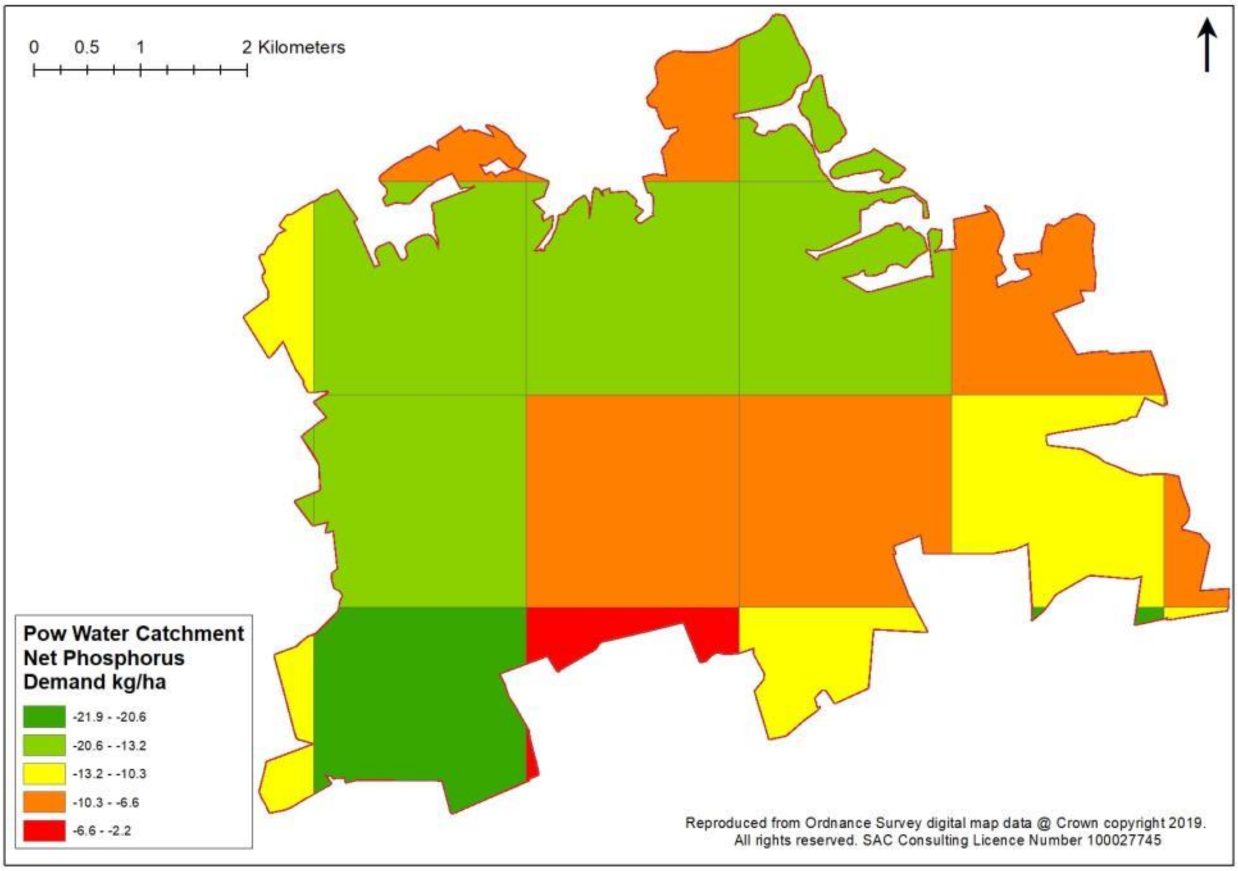

Figure 7.6. Net P demand at the catchment scale for the Pow Water catchment.

This data set shown in Figure 7.6 represents crop nutrient requirements after the fertiliser value of animal livestock manure and slurry has been accounted for. Negative numbers indicate a net demand indicating the need or opportunity to apply bagged fertiliser and/or import organic fertilisers to meet crop requirements. Positive numbers indicate a surplus due to intensive livestock production and the supply of nutrients are higher than crop need.

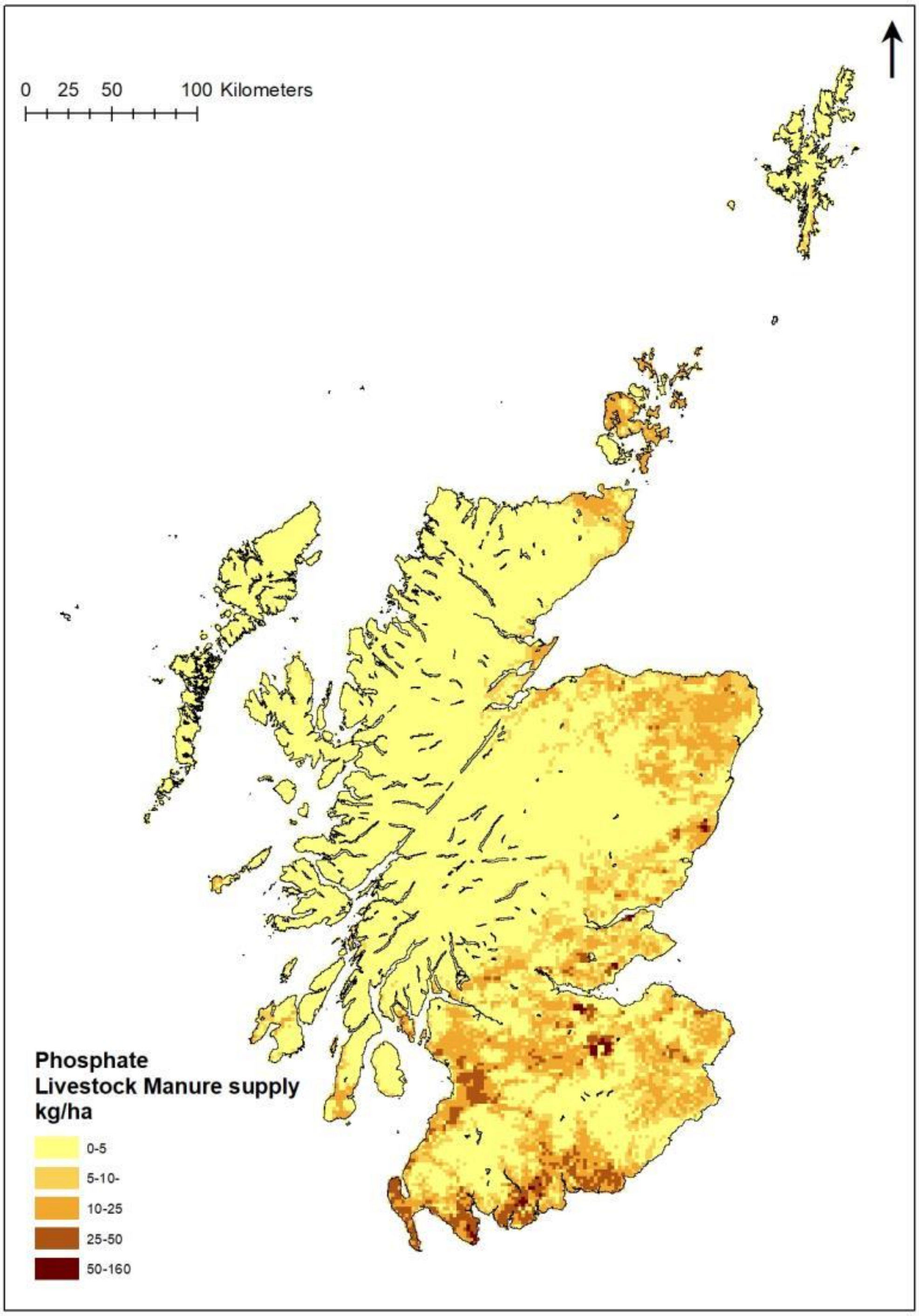

Figure 7.7. Phosphate supplied by livestock manure and slurries.

Figure 7.7 shows the total annual production of P being produced by livestock per 2 km^2 based on the 2015 agricultural census. This data set accounts for livestock type and includes the contribution made by bought in feeds. It is assumed that the nutrients are applied to the land to meet crop demand.

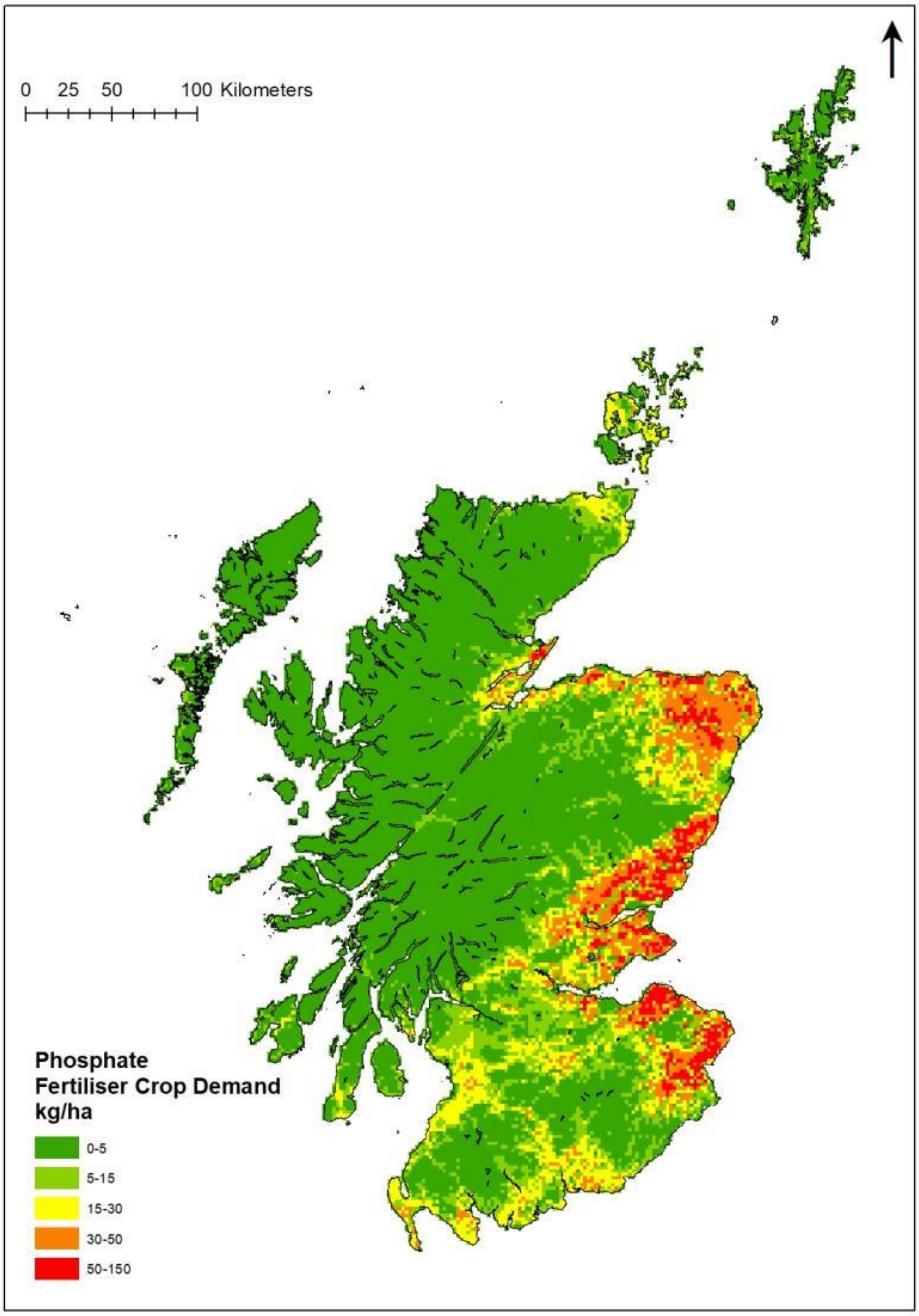

Figure 7.8. Fertiliser crop demand – phosphate.

This data set represented in Figure 7.8 shows the total crop demand based on the 2015 Agricultural census and the British Survey for fertilisers. The data shows “actual” fertiliser usage.

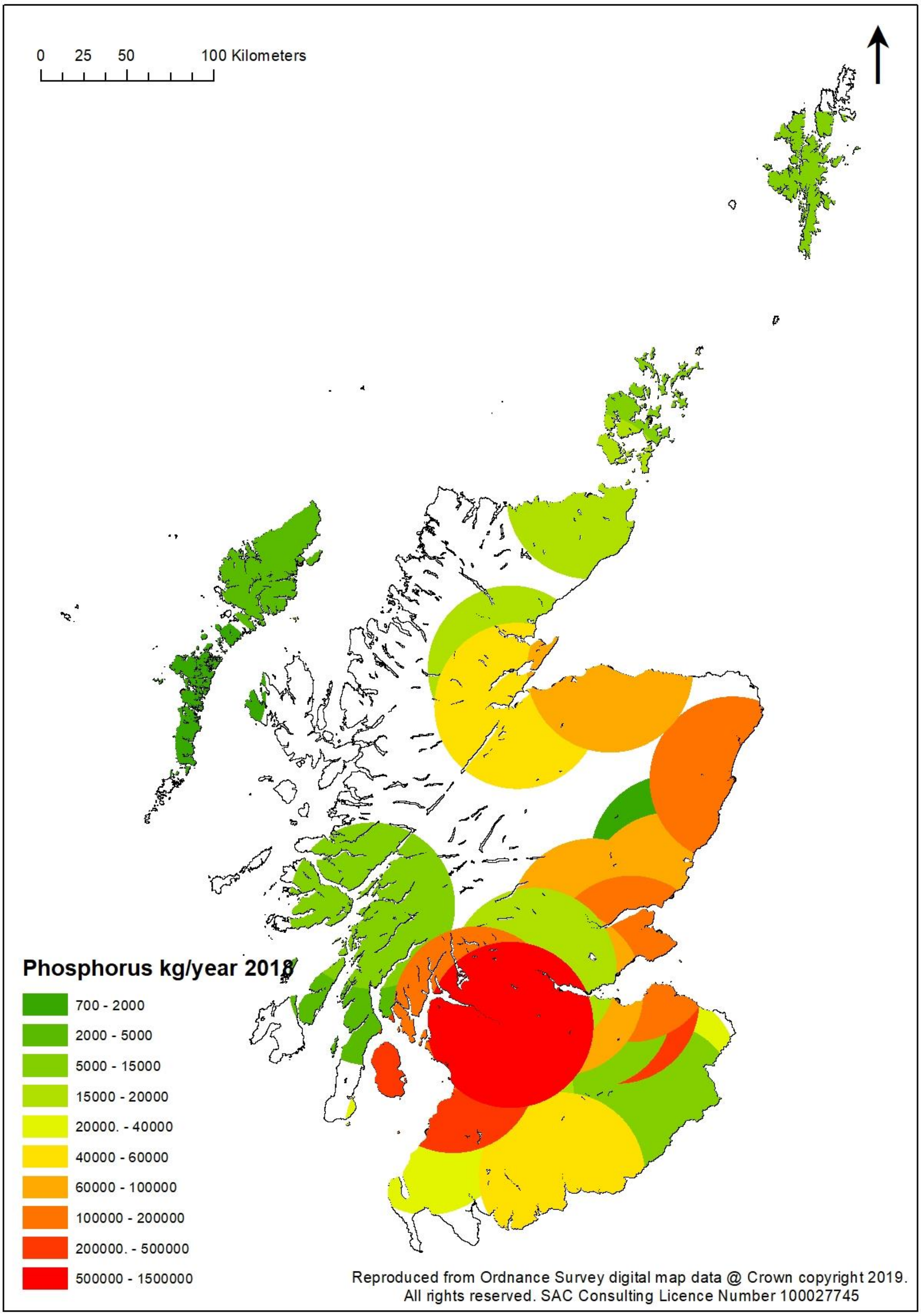

Figure 7.9. The location of Scottish Water facilities with potential phosphate supply, based on 2018 sludge production data and an indicative 30 km spreading radius.

The data represented in Figure 7.9 does not reflect current spreading practices e.g. material in Shetland is disposed of to landfill, rather than applied to agricultural land.

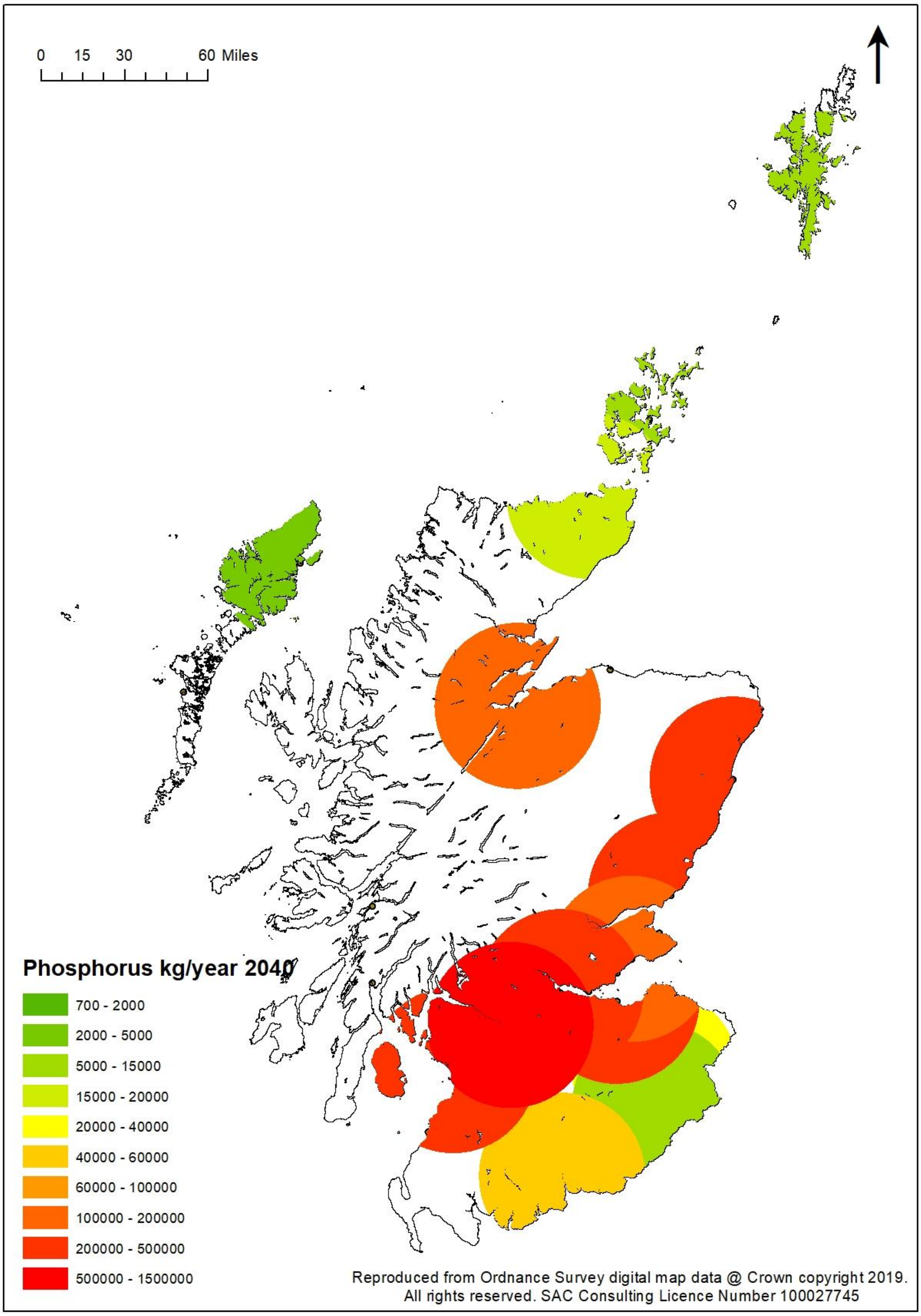

Figure 7.10. The location of Scottish Water facilities with phosphate loadings, based on projected figures for 2040 and indicative 30 km spreading zones.

This data set illustrated in Figure 7.10 is a graphical representation of the proposed future locations and processing capacity (converted to P output) of Scottish Water facilities.

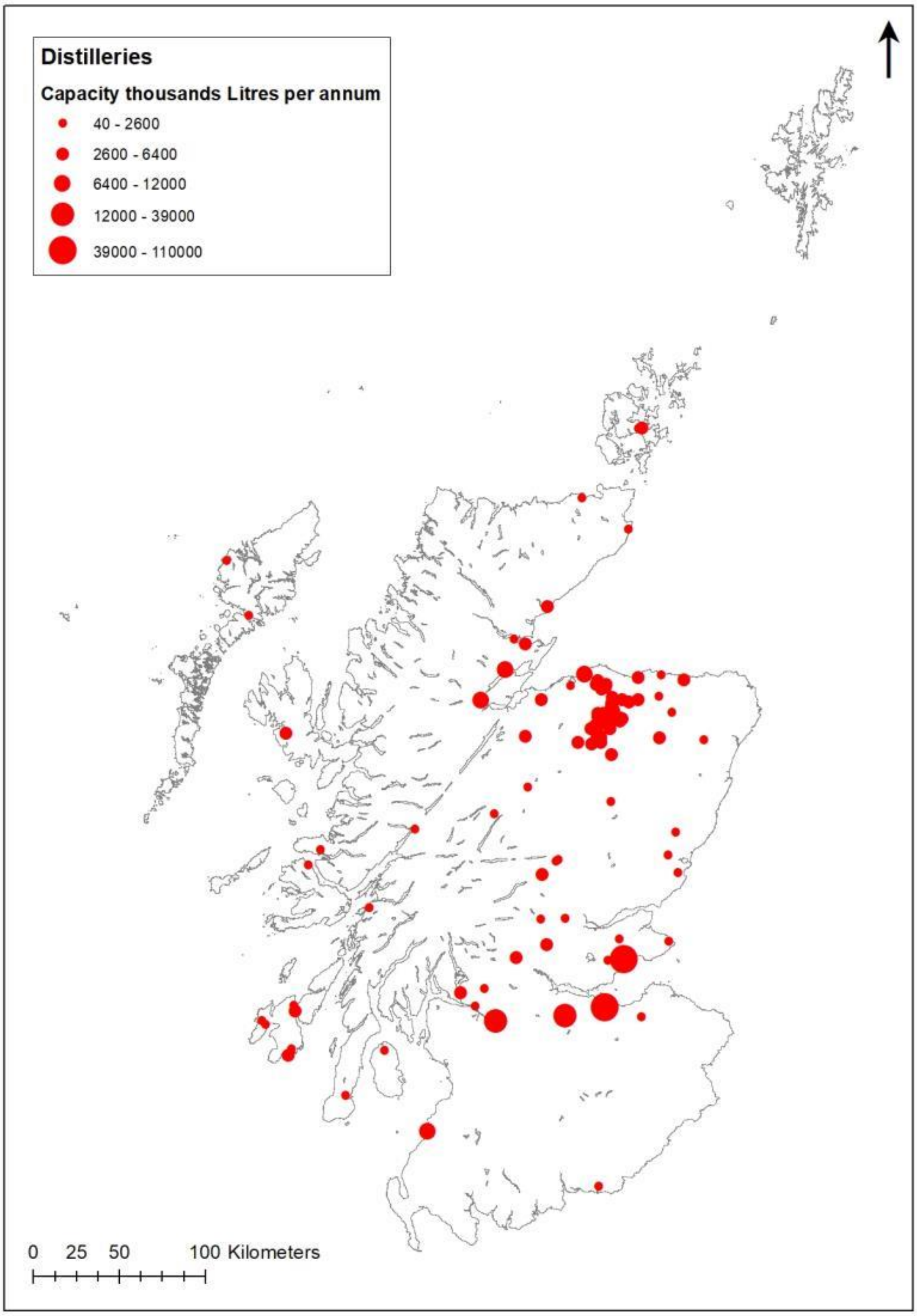

Figure 7.11. Location and total potential production capacity of distilleries across Scotland.

There is limited publicly available information on the location of distilleries and on the amount of organic materials available annually for land spreading from each one. Production capacity is used as a proxy for the potential amount of spreadable organic materials that may be generated but it is recognised that this is unlikely to provide accurate tonnages.

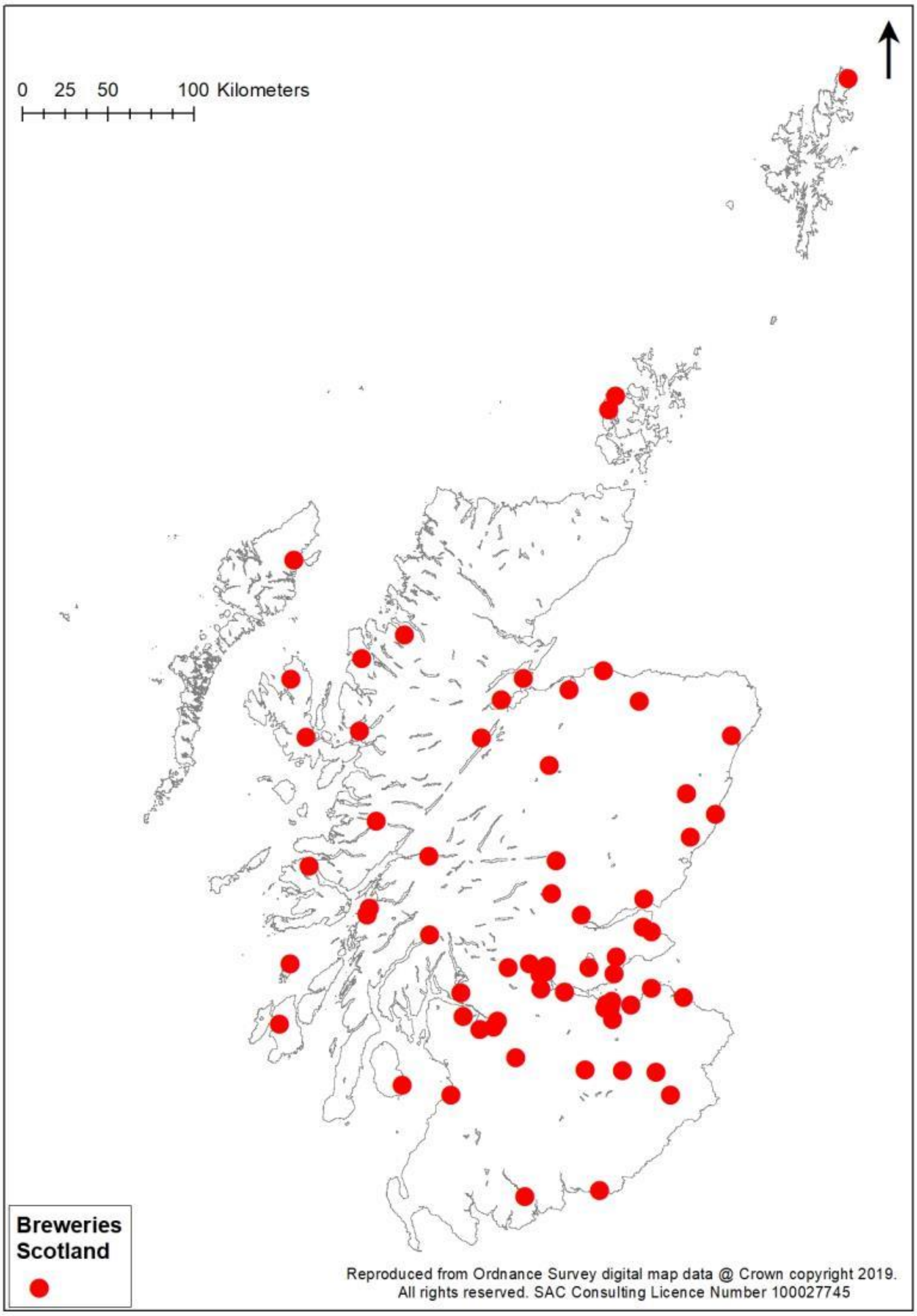

Figure 7.12. Location map of breweries obtained from publicly available data.

No direct or proxy indicators of the amount of nutrients available for land spreading that are arising from these facilities is available. The accuracy of this data set cannot be assured as there is currently no reliable means of obtaining accurate and relevant information.

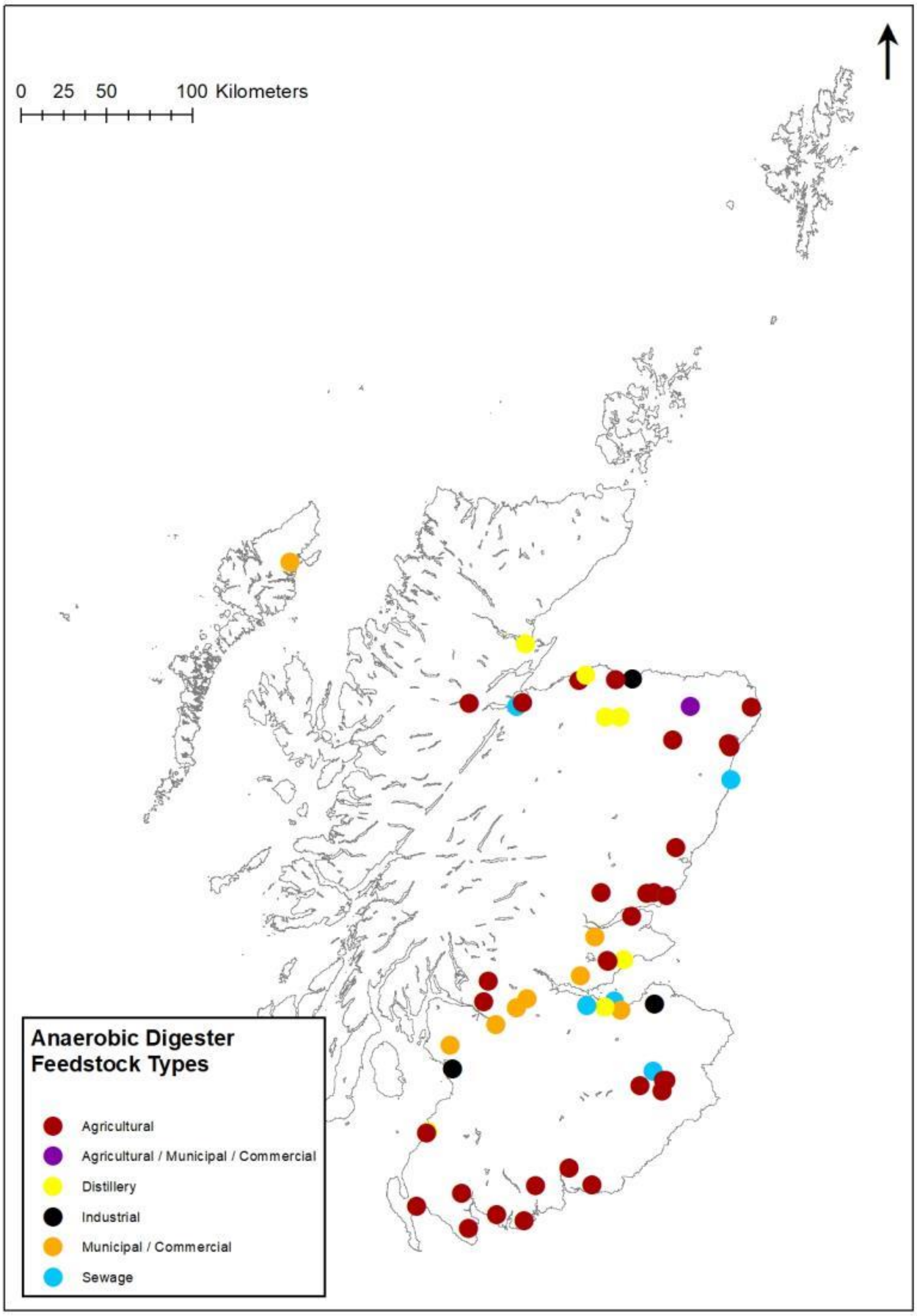

Figure 7.13. The locations of AD plants obtained from publicity available data sets showing reported feedstock type.

The accuracy of this data set cannot be assured as there is currently no reliable means of obtaining accurate and relevant information.

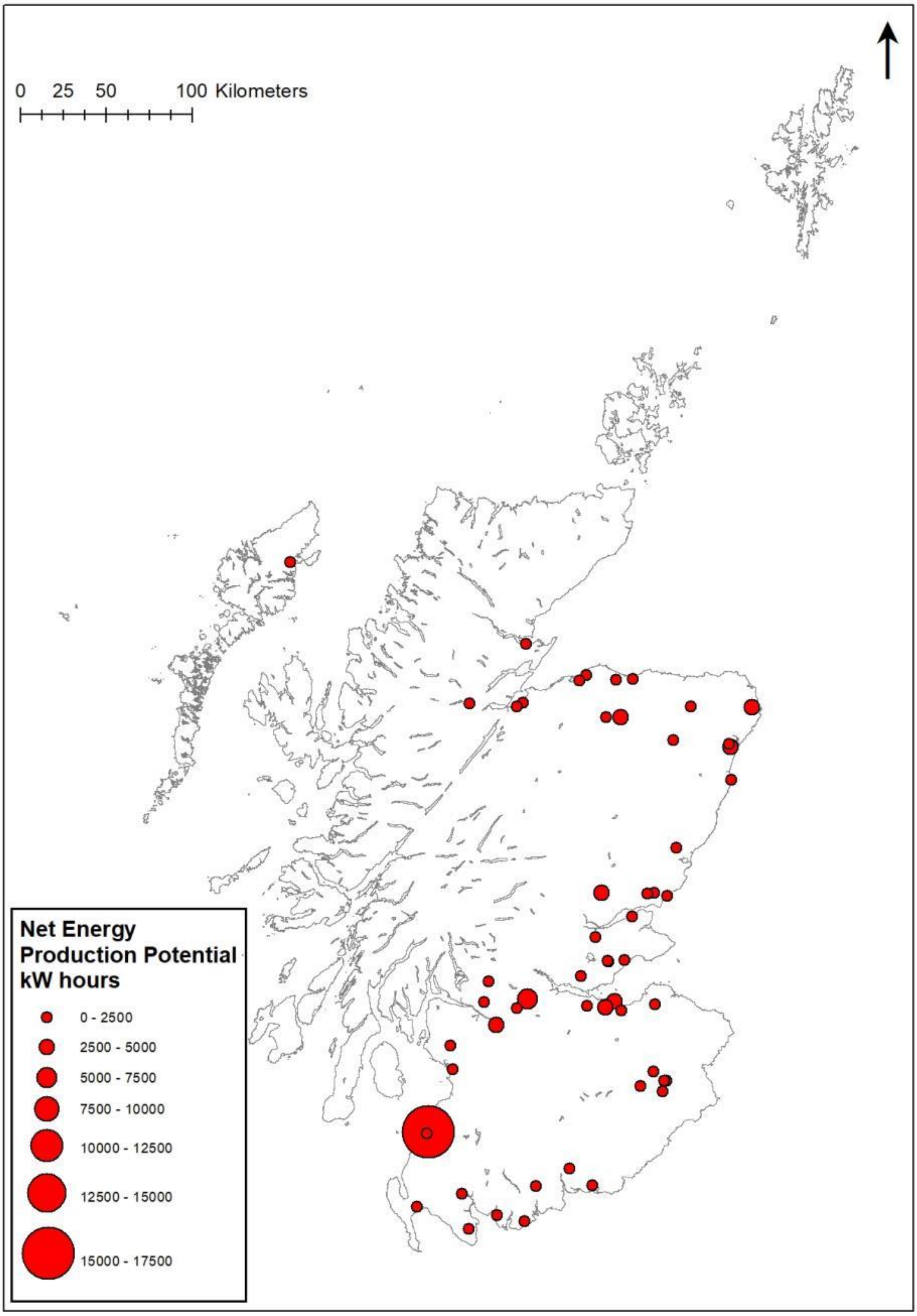

Figure 7.14. The locations of AD plants with net energy production potential (includes both thermal and electric).

The accuracy of this data set represented in Figure 7.14 cannot be assured as there is currently no reliable means of obtaining accurate and relevant information.

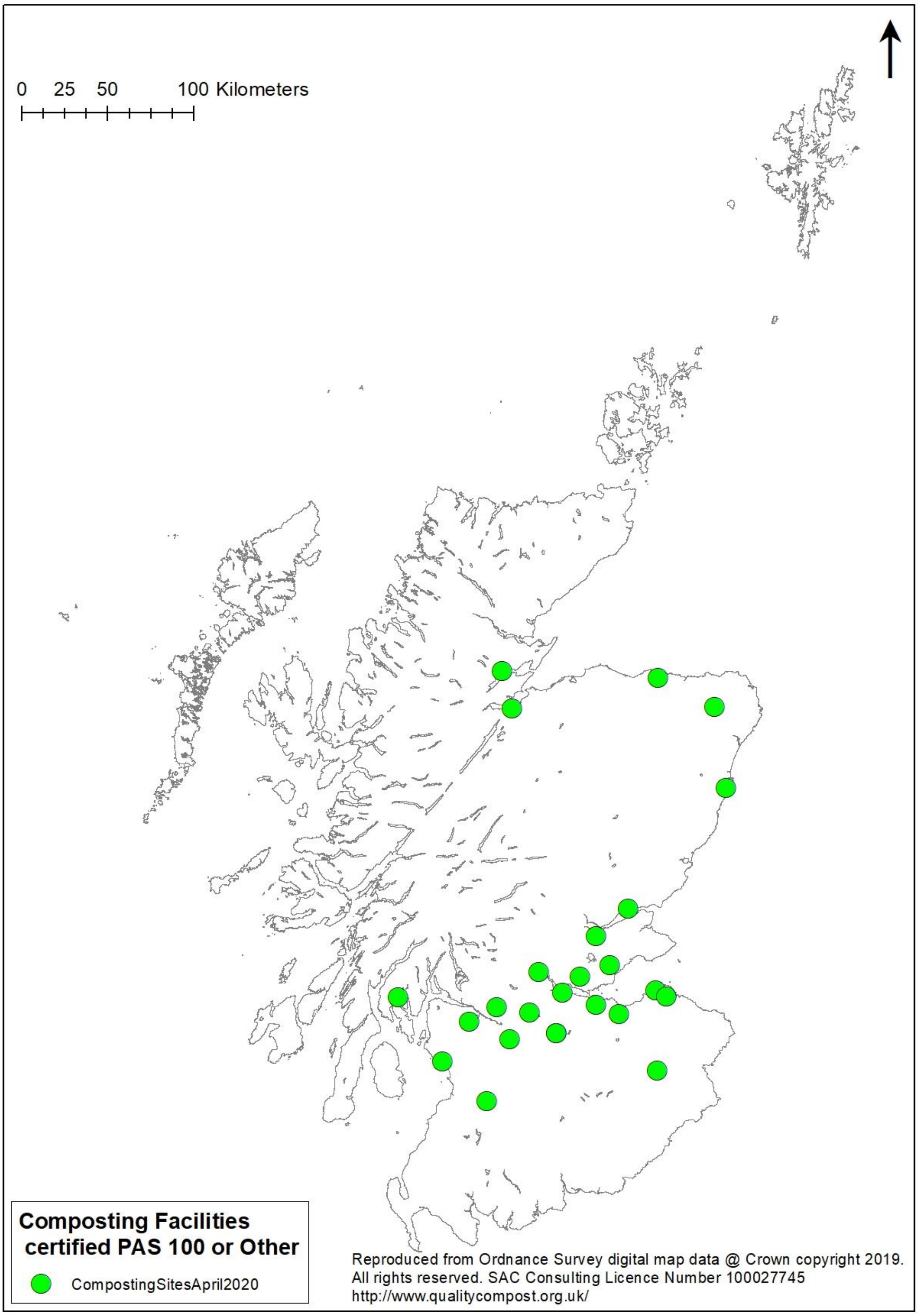

Figure 7.15. The location of composting facilities that are registered under the compost certification scheme.

The accuracy of this data set represented in Figure 7.15 cannot be assured as there is currently no reliable means of obtaining accurate and relevant information.

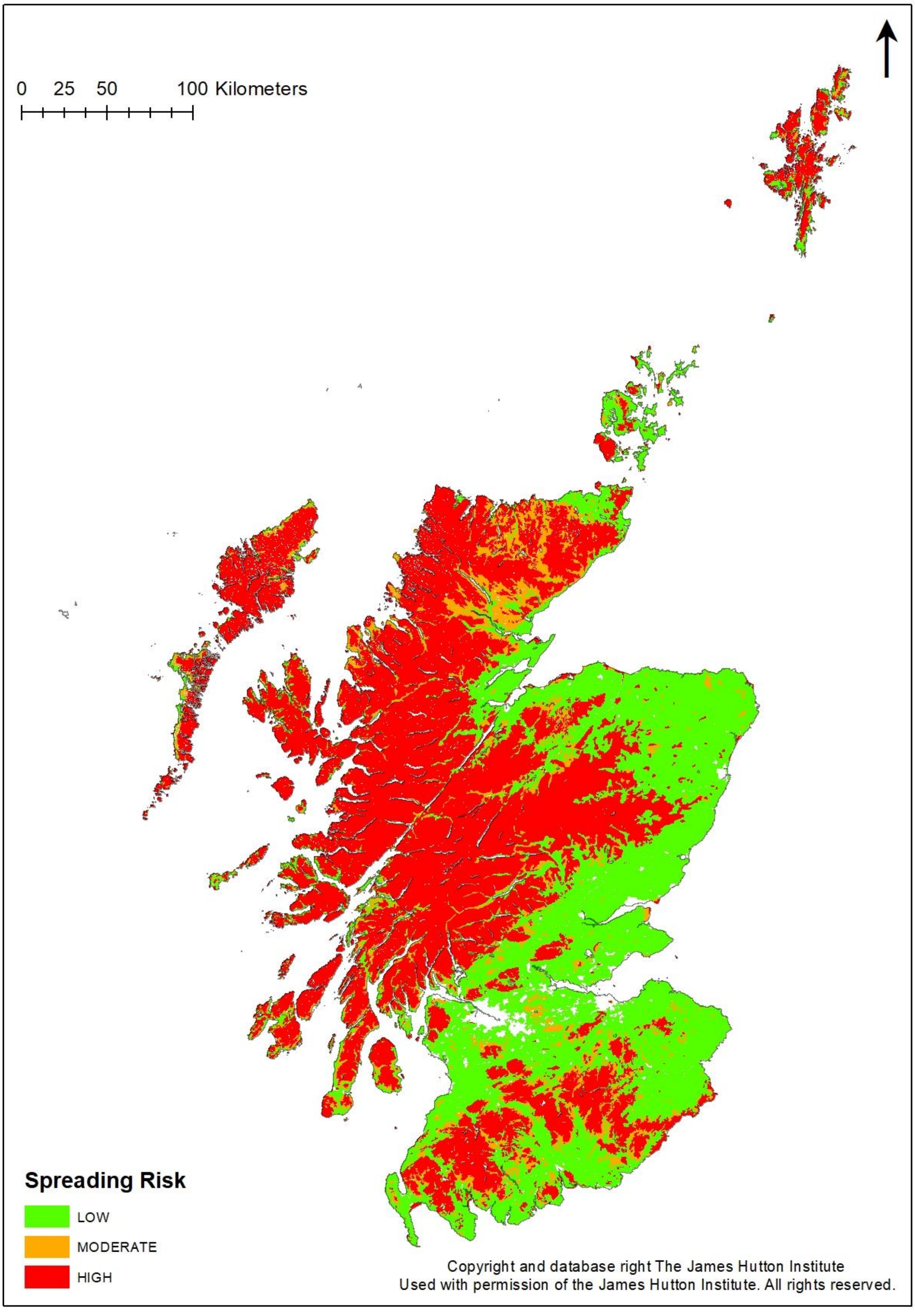

Figure 7.16. Map of Scotland showing the risk of land spreading based on the agricultural potential for production.

Low Risk indicates areas where spreading has a higher potential to be beneficial. High risk shows area where there is little potential benefit and land spreading is not be justifiable.

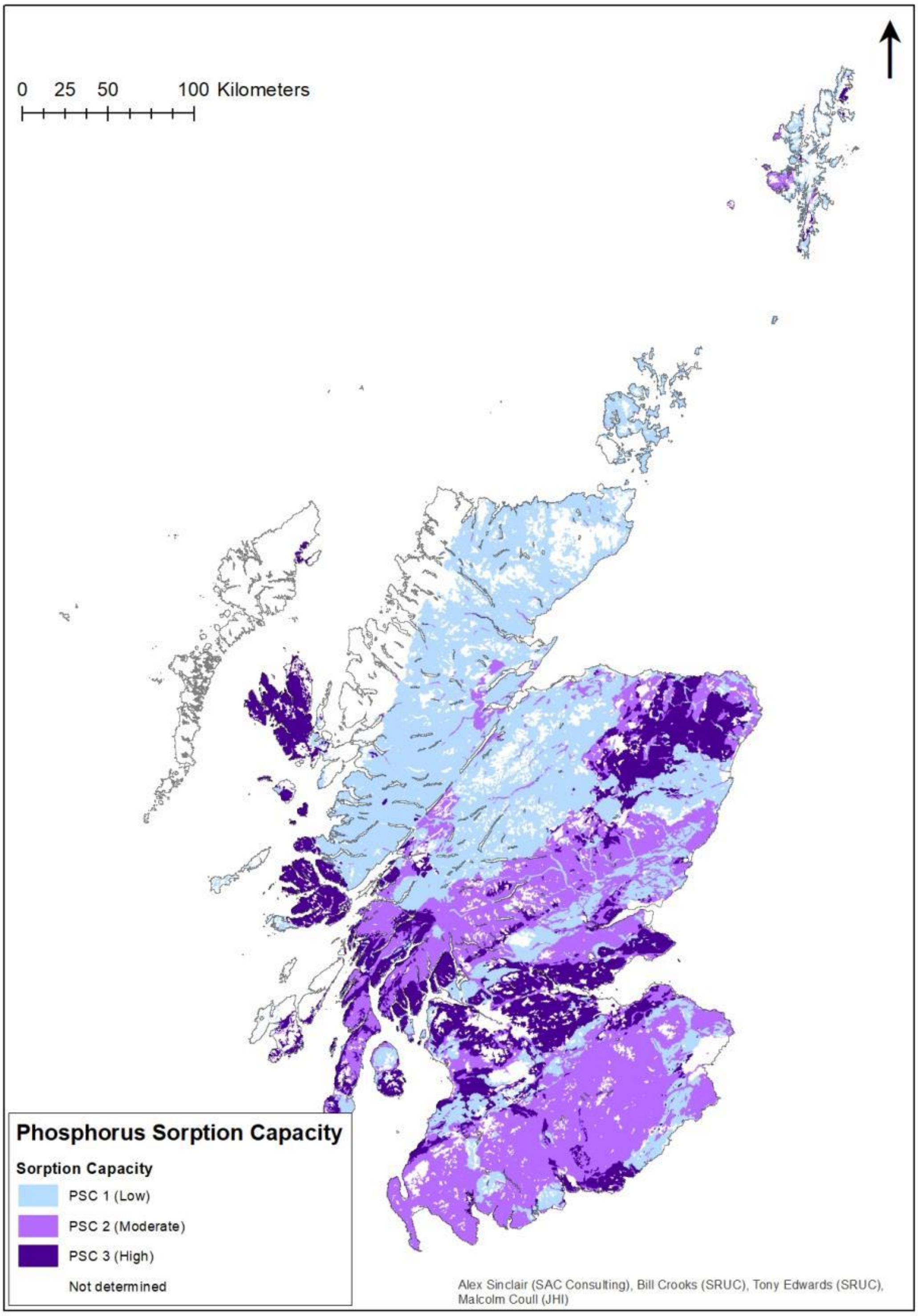

Figure 7.17. Soil phosphorus sorption capacity (PSC) map of Scotland.

Information in this data set is obtained from SRUC (2015).

Figure 7.18. Designated Nitrate Vulnerable Zones.

Information in this data set is obtained from Scottish Government (2016).

Appendix B
Working Example of GIS

The following details the application of a model that has been applied to the GIS data set to provide an example of how the data set can be applied in practice. The example in Figure 7.19 gives a graphical representation of the extraction of data to identify the spreadable land base in a user specific inter-catchment. In this instance the user is requesting a GIS output that shows the "spreadable" land base in the Perth and Kinross inter-catchment.

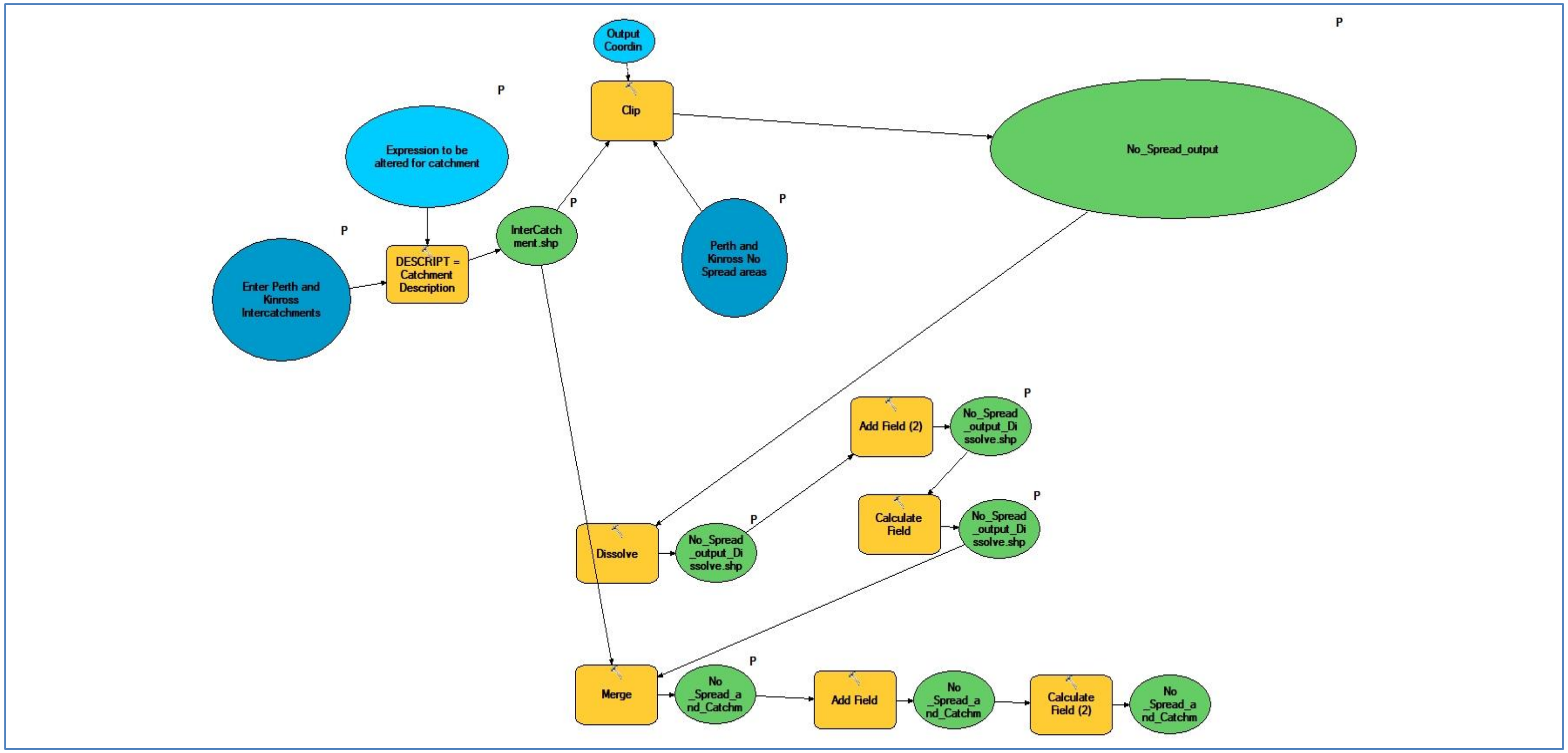

Figure 7.19. GIS output that shows the "spreadable" land base in the Perth and Kinross inter-catchment.

This is a basic model assembled in Arc Modelbuilder

Figure 7.20 shows the output of the above model (Figure 7.19). In this example a GIS layer containing inter-catchment boundaries was used to extract the area of land in the inter-catchment where there are no direct legal controls on the land spreading of organic materials. All area in red are classed as no-spread and must be discounted when determining the spreadable land base.

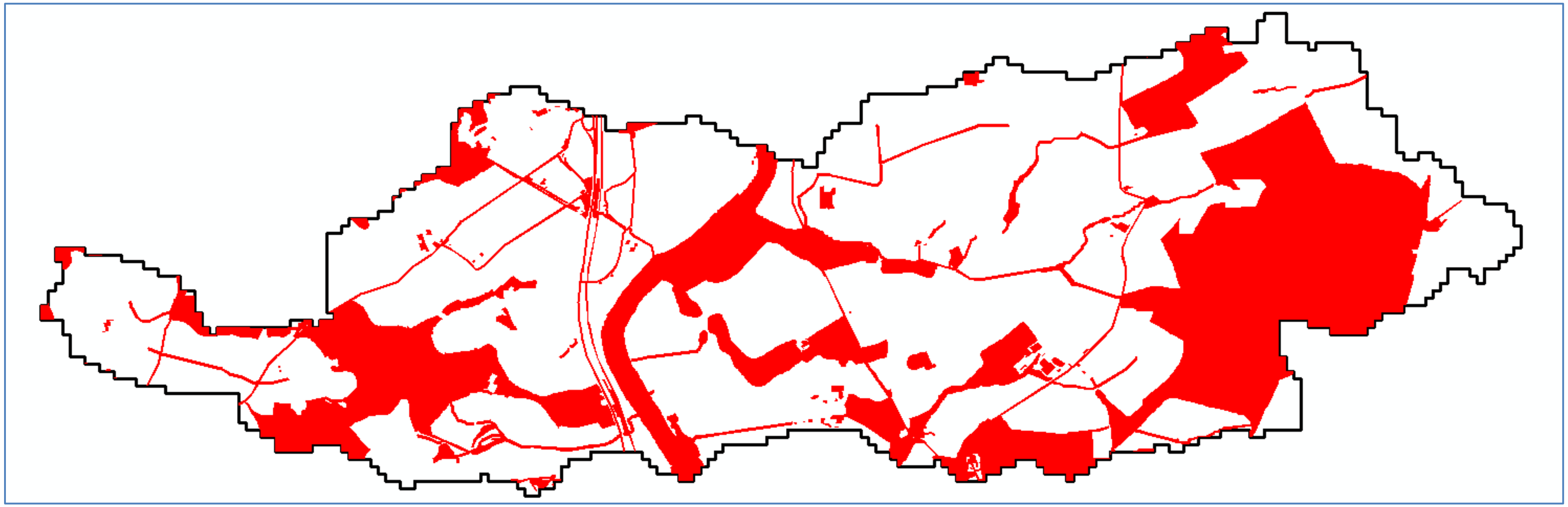

Figure 7.20. Graphical representation of model output showing the no-spread (Red) for the Perth and Kinross inter-catchment.

The model only requires the name of the inter-catchment to be added. All of the other datasets of no-spread and SEPA inter-catchment are stored within the model. Once applied, the fields and temporary files are created in the data to calculate hectarage by inter-catchment and no-spread within the inter-catchment. The remaining land (white) in Figure 7.20 has no direct limits on the spreading of organic fertiliser.

A more advanced application is demonstrated in Figure 7.21 showing Net Phosphate budget. Along with the no-spread zones marked in red (Figure 7.20), Figure 7.21 illustrates total crop demand that must be met by either bagged fertilisers or imported organic materials. This becomes a functional data set where total demand of phosphate over a given portion of a 4 km^2 area can be estimated numerically. In this example the entire inter-catchment has a net phosphate demand. However, the demand varies spatially with the eastern section having a notably lower overall requirement that the central section of the inter-catchment.

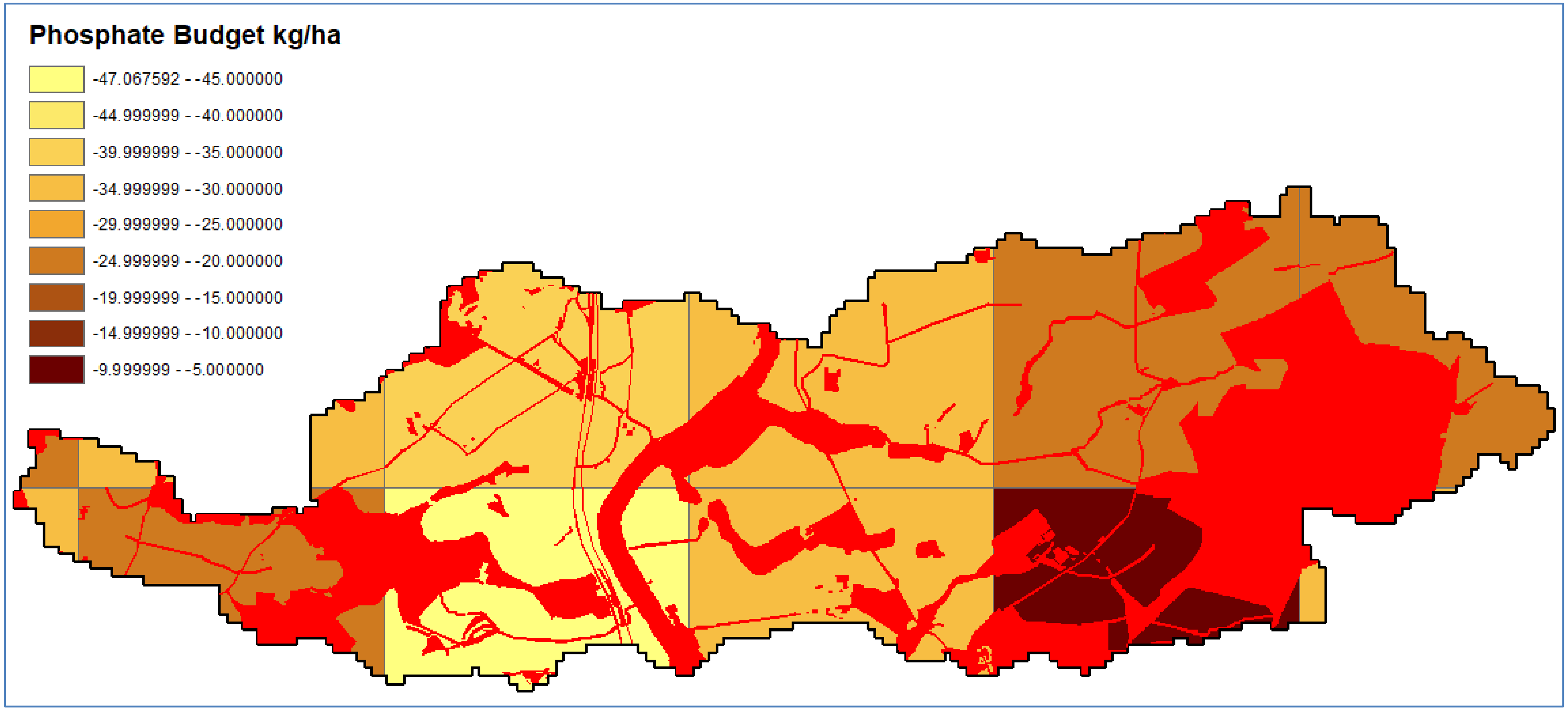

Figure 7.21. Addition of net phosphate requirement to meet crop demand with inclusion of no-spread data.

This illustrates the net requirement for either bagged or imported organic fertilisers needed to meet remaining crop demand.

8 Glossary of terms

Ammonia (NH_3): A gaseous compound composed of nitrogen and hydrogen, with a pungent odour.

Anaerobic: Condition where there is an absence of oxygen.

Anaerobic digestate: Organic material resulting from anaerobic digestion of biodegradable organic materials. The main types of digestate are whole digestate and separated (fibre and liquid) digestate.

Anaerobic digestion: A process whereby organic materials are broken down in the absence of oxygen to produce energy in the form of biogas and a nutrient-rich digestate.

Animal By-Products Regulations: A set of European regulations designed to ensure food safety under the ‘farm to table’ approach set out in the EU White Paper on Food Safety adopted in January 2000. They contain strict animal and public health rules for the collection, transport, storage, handling, processing and use or disposal of all animal by-products (ABPs).

Ash: Ash is produced from the combustion of solid fuels, including coal, peat and untreated wood.

Beneficial use: in the context of this report, “beneficial use” means that materials used in such a way will result in positive impacts on soils, crops, the wider environment, humans and other animals.

Biosolids: Sewage sludge which has been treated in order to reduce its human/animal pathogen content make it acceptable for recycling to agriculture under the Biosolids Assurance Scheme.

BSI PAS100:2018: Publicly available specification which covers the entire production process for composts and ensures that composts are quality assured, traceable, safe and reliable.

BSI PAS110:2014: Publicly available specification which covers the entire production process for anaerobic digestate and ensures that digestates are quality assured, traceable, safe and reliable.

Bulk density: The mass per unit volume of materials.

Carbon dioxide (CO_2): A colourless, odourless, tasteless gas that is produced as a result of respiration by plants and animals, including most microorganisms.

Compost: A stable, sanitised, organic material, which has been made commercially through mixing, self-generated heating and aeration.

Composting: The natural breakdown of biodegradable materials through mixing, self-generated heating and aeration to form a stable, organic material.

Crop available: The amount of nutrients (e.g. phosphate and potash) available to a crop in the (next) growing season.

Crop available nitrogen: The readily available nitrogen that remains for crop uptake after accounting for any losses of nitrogen. This also includes nitrogen released from organic forms.

Denitrification: Microbial conversion of nitrate and nitrite in anaerobic soil to nitrogen gas or nitrous oxide.

Digestate: See Anaerobic digestate

Distillery residues: Liquid waste produced as a by-product of the production of alcoholic beverages.

Extractable nutrient (particularly phosphorus and potassium): The quantity of nutrient regarded as available to plants present in the soil as measured by laboratory analysis. The result will vary depending on the extractant used (e.g. Olsen's P vs. Modified Morgan's P).

Feedstock: The biodegradable materials present at the start of a composting or anaerobic digestion process.

Fly ash: Fly ash consists of fine particles of ash which rise with the flue gases following combustion of coal, peat, wood or other combustible material.

Greenhouse gas: A gas that contributes to the greenhouse effect by absorbing infra-red radiation. Carbon dioxide, methane and nitrous oxide are the main greenhouse gases.

Green waste: Grass cuttings, leaves and pruning's, from parks or gardens.

Inter-catchment: An area of a river catchment which sits between two named tributaries.

Landbank: land which is available for the spreading of some or all types of materials in agriculture, forestry, amenity and brownfield land restoration.

Leaching: Process by which water-soluble substances such as nitrate or sulphate are removed from the soil by drainage water passing through it.

Liming value: Property of a material (measured as a neutralising value) that increases soil pH.

Major nutrient: Essential element required in large quantities from soils by plants, e.g. nitrogen, phosphorus and potassium.

Micro nutrient: Essential element required in small quantities from soils by plants (e.g. boron, copper, manganese, zinc etc.). Cobalt and selenium are taken up in small amounts by crops and are needed in human and livestock diets.

MANNER-*NPK*: A decision support system that will predict the nitrogen, phosphorus and potash value of applied organic materials, taking into account soil type, application timing/technique and ammonia, nitrate and denitrification losses.

Manufactured topsoil: Material produced by combining mineral matter and organic matter (and, where appropriate, fertiliser and lime), and which provides the same function as topsoil.

Micro-organism: An organism too small to see with the naked eye that is capable of living on its own.

Mineral soil: A soil mainly comprised of mineral material, with less than 10% organic matter.

Mineralisation: Microbial breakdown of organic matter in the soil, releasing nutrients in plant-available inorganic forms.

Nitrate (NO_3): Nitrate is soluble in the soil solution and can be leached as drainage water moves through the soil.

Neutralising value: See liming value

NVZ: An agricultural area which has been designated as being at risk from nitrate pollution by the regulations which implement the EU Nitrates directive in Britain.

Nitrous oxide (N_2O): A potent greenhouse gas that is emitted naturally from soils, especially where high nitrate concentrations and anaerobic conditions exist.

Organic material: Material derived from any living organism (e.g. livestock, human, plants) that supplies organic matter together with plant nutrients, usually in lower concentrations compared with manufactured fertilisers.

Paper crumble/sludge: The residue from the preparation of recycled paper prior to its re-use in the paper production process, or from the processing of virgin fibre from a variety of fibre sources, such as wood or cotton.

PAS100:2018: See BSI PAS100:2018.

PAS110:2014: See BSI PAS100:2014.

Pathogen: Any organism capable of producing disease through infection.

pH: A measure of the concentration of hydrogen ions in solution. pH below 7 = acidic, pH above 7 = alkaline.

Pot ale: Pot ale (also known as burnt ale or spent wash) is a high-protein residue from distillery wash stills.

Potentially toxic elements: Chemical elements that have the potential to cause harm to humans, animals, plants and/or microorganisms.

Readily available nitrogen (RAN): Nitrogen (i.e. ammonium and nitrate-N) that is potentially available for rapid crop uptake.

Safe: in the context of this report, “safe” means: without causing harm to crops, wild plants, humans, animals or the environment now and in the future”.

Sewage sludge: A solid, liquid or semi-solid waste obtained from the treatment of municipal sewage.

Soil conditioner (or soil improver): Organic material added to the soil to primarily maintain or improve its physical properties, and which can also improve its chemical and/or biological properties.

Soil organic matter: Often referred to as humus. Composed of organic compounds ranging from un-decomposed plant and animal tissues to fairly stable brown and black material, with no trace of the anatomical structure of the material from which it was derived.

Subsoil: Soil layer extending between the topsoil and the little weathered material below, or material that functions as subsoil in a constructed soil in a landscaping project on to which topsoil can be spread. Typically, subsoil has a lower concentration of organic matter and available plant nutrients than topsoil.

Sustainable use: in the context of this report, “sustainable use” means that materials are being used in such a way that they can be used indefinitely in the prescribed manner without causing harm of any sort. In some cases (particularly for finite resources, such as the annual tonnage of compost from an organics recycling site) it can also mean that the material is used in such a way that supplies of it are not depleted unnecessarily by applying more than the minimum required to provide benefit at each locations.

Topsoil: The upper layer of an in-situ soil profile, usually darker in colour and more fertile than the layer below (subsoil), and which is a product of natural chemical, physical, biological and environmental processes. The thickness of a natural topsoil varies with land use and management from only 100 mm to 300 mm in some sites to more than 350 mm in deeply cultivated agricultural sites.

Volatilisation: Loss of nitrogen (as ammonia) from the soil to the atmosphere.

Water treatment cake (sludge): Water treatment cake (sludge) is the residue resulting from the treatment of raw water to produce potable water in water treatment works.