Review of Restoration Achievements at two Scottish Opencast Mines

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1 Executive summary

There was a limited amount of evidence to link past restoration practices with restoration outcomes and very little was known about the long-term effectiveness of using sewage sludge in topsoil creation. There was therefore a clear requirement to gather evidence on the success of past restoration projects bearing in mind an understanding of the restoration techniques used (including information on waste types used, tonnages applied, compaction relief and subsoil and topsoil manufacture where possible).

The overall aim of this project was to establish the impact of sewage sludge applications used during restoration of two former opencast coal mines and in particular to assess whether restoration objectives have been achieved. Both study sites should have been restored (at least in part) to agriculture including extensive grazing.

The project had three key aims as follows:

Objective 1 (Site and soil investigation): To assess six study areas on each of the two former opencast coal mines by characterising the vegetation, assessing the topsoils and soil profiles and by testing key soil chemical and physical properties through laboratory analysis.

Objective 2 (Data analysis and interpretation): To assess the success of the restoration in each of the study areas (in terms of soil properties and the establishment/growth of desirable plant species) and relate that (as far as possible) to restoration techniques used.

Objective 3 (Recommendations): To make recommendations for the success of future restoration schemes.

Assessment methods

Available information on restoration practices used on each site was reviewed in early Spring 2017. Each of the two sites was visited on at least four occasions during the summer of 2017. Sites were visited initially for 2 to 3 days of staff time (in total) during late May and early June to set priorities and practical plans for further assessments. Vegetation analysis on both sites was conducted in mid July. Full soil physical examinations and soil profile assessments followed in August and samples were taken on that occasion for laboratory analysis.

Site 1 – findings and summary of degree of success of the restoration

This site was restored between 2011 and 2014. Six study sites were selected, five of which were restored and one of which had not been restored.

- During the site visits, the land (in all five restored areas) was unsafe to walk on, and unsafe for livestock (a key end use for this site was agricultural grazing). The dangers were due to both the poor land forming in some parts (prior to restoration), which had left steep areas, hollows and open ditches, some of which were covered in vegetation and filled with water. The hazardous nature of the site was compounded by the amount of rock, brick, concrete and general rubbish which was abundant in parts. There were no gates or fences to contain livestock. The vegetation present on the site was often dense and vigorous, but it lacked diversity. The vegetation was dominated by weed species of low ecological value which had extremely limited forage value for livestock.
- The primary potential environmental concern for the restoration outcomes at Site 1 was the continued presence of a discrete layer of sewage sludge within the soil profile, in all five of the restored areas investigated, 4 years after restoration was completed. In each instance, the remaining layer of sludge was at or below 300 mm. There was therefore little prospect that the benefits of sludge as a topsoil forming material and plant nutrient source will be realised. There is also a risk of subsidence and of leaching of nutrients (especially P and nitrate) into surrounding watercourses and water bodies.
- The overall conclusion from the investigation was that the restoration at Site 1 was not successful. The site is completely inappropriate for any form of agricultural use as it stands, it is unsafe for public access, is of

limited value for wildlife and poses some degree of risk to the surrounding environment due to the potential for P to leach into local watercourses.

Site 2 - findings and summary of degree of success of the restoration

This site was restored between 2013 to 2015. Six study sites were selected, five of which were restored and one of which had not been restored.

- The land forming has been completed to a high standard at Site 2, there were few surface rocks and stones, the land has been fenced, gated and livestock are now grazing on established swards. Given that the intended end use for the restored land there was agricultural grazing and the land is now functioning either very well or fairly well for that purpose, the restoration can be classed as being successful, at least to some extent. However, the soil profile investigations revealed problems with soils in Areas 3, 4 and 5.
- The degree to which the restoration can be classed as successful differs markedly between Areas 1 and 2 (where sludge was surface applied and disced in) and Areas 3, 4 and 5, where (information was provided from the land restoration contractor that) a double digging approach was used.
- Areas 1 and 2 show the results of good restoration practice, with a well-drained topsoil with evidence of structure development, overlying a suitable subsoil. Soil analysis showed that the environmental risk was low and the agricultural potential very good. The thriving vegetation was made up mainly of sown species of good forage value. The land is being managed well and is likely to continue to improve in terms of its agricultural productivity.
- In Areas 3, 4 and 5 although the majority of the vegetation was made up mainly of sown species of good forage value, large, aggressive weeds were frequent in these areas. Soil profile investigation revealed layers of buried sludge at inappropriately low depths (in some cases as deep as 700 mm at the lower limit) in all three areas. The environmental risk was high in these areas, due to the presence of these readily available nitrogen (RAN)/phosphate (P)-rich buried sludge layers. Both nutrient leaching and topsoil subsidence are likely over time. The agricultural potential was only moderate, because soil nutrient status was generally low or very low and pH was very low in the topsoil. (The nutrients were generally buried in the sludge layer, which was usually below rooting depth.) The land is being managed well, but future improvements may be impaired by the lack of nutrients in the topsoil and the long-term impact of the buried sludge layer.

Recommendations based on project work and experience on related projects

Recommendations were based on work done in this project and on experience in related projects. Twenty six recommendations were made, concerning the following topics:

- Waste Management Licence Exemption (Paragraph 9) [or subsequent equivalent] application
- Final land-forming prior to final restoration
- Compaction relief
- Application rates
- Permitted organic materials
- Application methods
- Recording and monitoring of work done
- Post-restoration management
- Need for clear guidance on permitted land restoration techniques
- Funding of future restoration permits and compliance monitoring

2 Introduction and background

Due to its geology, the central belt of Scotland has had numerous opencast coal mines, which together covered considerable land areas, mainly in Ayrshire, Lanarkshire and Fife. Most of these are no longer worked, with a few having been restored or partly restored, some currently undergoing restoration and many at present lying abandoned and derelict. Once mining has ceased, the sites tend to be characterised by the presence of clay-rich drift material and/or shale. There is usually a marked absence of topsoils and the soil-forming materials present are often highly compacted due to the use of heavy machinery. The sites often look un-natural when viewed from nearby, with steep-sided bings and irregularly shaped dumps of rock/soil and large expanses of barren ground.

Former opencast mines require active restoration in order to bring them back into useful condition, for example for agriculture, forestry, amenity or as sites for industrial or domestic buildings. In the UK, restoration often involves the use of waste organic materials in order to improve existing soil-forming materials with the long-term aim of producing functional topsoils. Restoration of former opencast coal mines is an extremely costly operation, with requirements for moving large tonnages of rock, subsoil and topsoil-forming constituents in order to re-shape the land to make it more useful (depending on the end use), natural looking and safe (in terms of both human/animal access and environmental protection). Topsoil amendment and/or topsoil formation is an additional costly job which must be done in most cases in order to create a functional restored landscape.

Funds for land restoration are extremely limited. Site owners and/or companies responsible for site restoration usually largely fund (or part-fund) restoration by charging a "gate-fee" to waste producers which supply soil amendments/topsoil-forming constituents in the form of waste materials to each site. The use of waste materials is principally encouraged by a number of policy instruments that are designed to increase the recycling of materials e.g. the Waste Framework Directive, targets associated with the Landfill Directive, and Scotland's Zero Waste Plan. Waste organic materials are effectively the "engine" which drives ongoing restoration of derelict sites in Scotland. Given the high costs involved and the lack of funds from elsewhere, restoration would be unlikely to happen widely if it were not for the money associated with the transfer of waste materials on to sites requiring restoration. Although a range of waste materials are used in land restoration, including off-specification composts, canal sediments, recycled aggregates, clean water sludges and paper crumble, various forms of sewage sludge (SS) (including treated and un-treated sludges) remain the most frequently used sources of both nutrients and organic matter used in the restoration of opencast coal sites. This is because greater tonnages of sewage sludge (particularly untreated sludge) are available for land restoration than other wastes, mainly because there are limited markets for them elsewhere.

Whereas SEPA can set limits to the quantity of the waste material applied, the current regulation doesn't allow provision of specific conditions on waste application methods, wider constraints or post-restoration management (which can be crucial to restoration success). There is a strong argument for changing the relevant regulations in ways that would be likely to favour optimum restoration outcomes. Under the Regulatory Reform Act, it is envisaged to bring site restoration activities under a permit. This will enable SEPA to set more specific conditions. Not only will they be able to determine the amount of material to be applied but also the methods, subsoil improvement and aspects of post-restoration management.

Some independent soil scientists and specialists within SEPA feel that the current practice of purely adding substantial amounts of nutrient and organic matter rich material is neither necessary or beneficial (in terms of achieving optimal restoration outcomes). Sewage sludge is high in organic matter and nutrients, but a significant proportion of the organic matter is labile and easily decomposable. A high percentage of the nutrients present are therefore available in the first year when plant establishment is often poor. Nutrient uptake is therefore limited and nutrient losses (especially of nitrogen (N)) through leaching or emissions to the atmosphere can be high.

There is a limited amount of evidence to link past restoration practices with restoration outcomes and very little is known about the long-term effectiveness of using sewage sludge in topsoil creation. There is therefore a clear requirement to gather evidence on the success of past restoration projects bearing in mind an understanding of the restoration techniques used (including information on waste types used, tonnages applied, compaction relief and subsoil and topsoil manufacture where possible).

3 Project aim

The overall aim of this project was to establish the impact of sewage sludge applications used during restoration of two former opencast coal mines and in particular to assess whether restoration objectives have been achieved. The study focussed on two sites, both of which should have been restored (at least in part) to agriculture including extensive grazing.

The project had three key aims as follows:

Objective 1 (Site and soil investigation): To assess six study areas on each of the two former opencast coal mines by characterising the vegetation, assessing the topsoils and soil profiles and by testing key soil chemical and physical properties through laboratory analysis.

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Objective 3 (Recommendations): To make recommendations for the success of future restoration schemes.

4 Sites studied

Two sites were chosen based on the landowner's willingness to take part in the project combined with the availability of information on restoration practice and intended restoration outcomes. Information was based on Waste Management Licence Exemptions (WMLEs) submitted to SEPA. Verbal information on intended restoration outcomes, restoration practice and post-restoration management was also obtained for site 2 from the restoration contractor. It was often very difficult or impossible to determine exactly what had happened in terms of restoration practice, particularly at the six areas under investigation at Site 1. WMLEs specify the total amount of named wastes to be used on the area concerned in each application, and the maximum application rate, so the application rate can (in theory at least) vary over the site).

4.1 Site 1

This former opencast coal site comprises approximately 545 ha. It was formerly owned by Scottish Coal and then an independent mining company. Parts of the site (we understand those parts encompassing Areas 3, 4 and 6) was sold early in the 21st century to an independent contractor, which was responsible for land restoration activities conducted on all restored parts of the site. The site is now in the hands of a different company, which has no plans for it at present.

4.2 Site 2

This former opencast coal site comprises approximately 700 ha. It was formerly leased from the owners by Scottish Coal and coal extraction ceased in 2013. After initial land-forming, the land took on an appearance which was broadly similar to what it looked like prior to coal extraction. Restoration was completed in 2014 and the land is now being managed by a tenant farmer as of 2016.

5 Survey methodology

The two restoration sites were chosen following discussions with SEPA in late 2016 and spring 2017 and following a review of available information on restoration practices used on each site. Each of these sites was visited on at least four occasions during the summer of 2017. Sites were visited initially for 2 to 3 days of staff time (in total) during late May and early June to set priorities and practical plans for further assessments (Section 5.2). Vegetation analysis on both sites was conducted in mid July (Section 5.3). Full soil physical examinations and soil profile assessments followed in August (Section 5.4) and samples were taken on that occasion for laboratory analysis (Section 5.5).

5.1 Restoration practices used

WMLEs state the total tonnage to be applied and the maximum application rate, but it is possible that different (lower) application rates can be used in some parts of a site. Higher application rates than the maximum rate stated on an approved WMLE should not have been applied over any part of a site.

At and around the time of the initial site assessments, as much information as possible was gathered on the restoration practices used at both sites. Information was obtained from SEPA in the form of historical paragraph 8 and 9 WMLEs and certificates of agricultural or ecological benefit. Additional verbal and written information on restoration practices, past and current management was also gained from the land restoration contractor at Site 2. Where possible, current and previous landowners (and in Site 1's case local people) were asked about site history, past management and original aims for restoration. This, along with notes on discrepancies apparent (following initial site surveys) between reported practice and likely actual practice is summarised in Sections 6.2 and 7.2. However, it was sometimes impossible to find out the actual application rates of materials used on different parts of a site, because no records, or poor records of what happened were available. There was also conflicting evidence of what had happened in some cases.

5.2 Initial site surveys

Sites were visited initially (for around 4 person days per site) in June 2017 in order to gain an overall view of the shape of the land, the vegetation cover and the soils present. Sites were comprehensively walked during this visit and safe access and parking points for vehicles were noted for future reference. Notes were made on the different parts of each site including their extent, slope, aspect and topography, the extent of plant cover as opposed to bare soil and the types of plant species present. Quick test digs were made to look at the texture, structure and drainage status of soils present. Notes made during these visits are presented in Appendix 1 (Notes from initial site surveys). Attempts were also made to identify differences between different parts of the site based on both visual assessments on the day and on written information in WMLEs obtained from SEPA. Six individual areas on each of the two sites were chosen for further study and these were agreed with SEPA before the full vegetation analysis, soil physical assessment and soil sampling commenced.

5.3 Full vegetation analysis

In early July 2017, each of the six study areas at both sites were walked by crossing from side to side in a zig zag pattern in order to gain an accurate record of the species present and their height, density and health. All species present in each study site were listed.

In addition to the above, ten detailed 1 m quadrat assessments were made in each of the six study areas at both sites. These were chosen to ensure that all broad combinations of plant species typical to the study areas were represented. The following were recorded in all quadrats:

- Plant species present;
- Abundance of plant species present in each quadrat (DAFOR scores were allocated to each species present in each quadrat. This means that each plant species was considered to be: dominant, abundant, frequent, occasional or rare within the quadrat [Appendix 2]);
- Overall percentage ground cover by higher plants;
- Mean and maximum height of the herbage;
- Health and condition of the plants present.

A score for "Ecological value" was assigned to the vegetation present in each of the six areas on each site. The five scores ranged from "very poor" to "very good" and were defined as follows:

- very (v) poor = very few species and/or a lot of bare soil;
- poor = relatively few species, and/or one or more weed species frequent or abundant (see DAFOR, Appendix 2) and/or some bare patches;
- moderate = most soil covered, moderate number of species but one or more weed species frequent or abundant;
- good = complete/almost complete soil cover, a reasonable range of flowering species from different families incl. grasses and non-grasses;
- very (v.) good: complete soil cover with a good range of flowering species from different families incl. grasses and non-grasses.

The scores were based on a combined assessment of the:

- total number of species;
- degree to which a very few species in the area were dominant or abundant (rather than there being a broad mix of species, all of which were similarly common in the area);
- percentage ground cover.

The scores were intended to reflect the value of the sward for wild animals and plants, which is likely to depend not only on species richness, but also on the other two factors noted above.

5.4 Soil physical assessment and soil profile characterisation

Each site was visited by three staff members for the purposes of detailed soil sampling and soil profile assessment during August 2017 (1st August at Site 2 and 14th/15th August at Site 1). Using a mechanical digger, a single soil pit was dug in each of the six study areas, to a target depth of 700 mm, depending on the nature of the profile found and to establish the full depth of the layers present. Each pit was dug within 8 m of the 10 figure

OS grid reference numbers on which each of the six numbered areas on each site were based to ensure its location overlapped with the detailed vegetation assessment.

A trowel and spade were used to further excavate the mechanically dug pits in order to gain a good understanding of the physical nature of the different layers in the soil profile. Methods described in the Soil Survey Field Handbook (Technical Monograph No. 5) were used where possible, but given that the soil profiles being examined were manufactured rather than natural, some of the terminology and description standards had to be modified.

A soil profile description was prepared for each pit, with descriptions of all layers to 700 mm depth. Particular attention was paid to the degree of mixing between original soil-forming materials (based mainly on sand, silt, clay and stones) and sludges (or other waste materials). The following in particular was noted for each pit:

- Soil texture and stone content (if organic, the type of organic material present);
- Soil structure (shape and size of peds, degree of ped development, voids, fissures and pores), and consistency. VESS (Visual Evaluation of Soil Structure) assessment (Ball et al., 2012);
- Presence and depth of compacted layers;
- Total depth of created soil;
- Drainage assessment;
- Soil colour; (see glossary)
- Smell (e.g. the presence of sulphurous odours indicating poor drainage/anaerobic conditions);
- Roots (size, depth and abundance)
- Earthworm counts and presence of fungal hyphae (visual assessment);
- Bulk density at approximately 250 mm and 500 mm depth (modified as appropriate in relation to each soil profile).

5.5 Soil analysis

Soil samples were taken from a single pit in each study area. Two (or in one case three) samples were taken from the layers of the “manufactured” soil profiles. The layers were (if present) upper soil profile (labelled as 1), any underlying mineral fraction which was distinct (labelled as 2) and from the unadulterated sewage sludge which was found in most of the pits in restored areas.

Soil samples were tested at NRM Laboratories Ltd. (Coopers Bridge, Braziers Lane Bracknell, Berkshire, RG42 6NS). Samples were cold stored at SAC Consulting’s Ayr base after collection until all samples were ready to be couriered to the lab and until the test suite was agreed with SEPA. The samples were sent off on 2nd October 2017, they were received by the lab on 3rd October and reported on 11th October 2017.

Mineral soil samples were tested for the following parameters:

- Soil organic matter content (Loss on ignition);
- Soil organic matter content (Dumas method);
- Total N, total C and C:N ratio;
- pH, extractable P, K and Mg (water extract for pH measurement, Olsen P for P and ammonium nitrate for K and Mg [ADAS methods]; $CaCl_2$ extract for pH measurement, modified Morgan’s reagent for P, K and Mg [SAC methods]);

- Total potentially toxic element concentrations (aqua regia Cd, Cu, Cr, Hg, Zn, Ni, Pb).

NB: SAC add “0.6” to pH results obtained using $CaCl_2$ extractant in order to make results directly comparable to those obtained from a water extraction. When using the Scottish methods for pH testing (i.e. when using $CaCl_2$ extractant) NRM do not add the 0.6. Given that NRM tested soils with both methods, this means that pH values for the same soil appear lower when $CaCl_2$ was used as an extractant rather than water.

Sewage sludge samples were tested for the following parameters:

- pH;
- Oven dry matter (%);
- Total N, ammonium-N, nitrate-N;
- Total P, K, Mg;
- Organic matter content (Loss on ignition);
- Total organic carbon (Dumas method);
- Water soluble P, K and Mg;
- Total potentially toxic element concentrations (aqua regia Cd, Cu, Cr, Hg, Zn, Ni, Pb).

5.6 Assessment of environmental risk and suitability for agriculture

The soil assessment process produced a considerable amount of analytical data that was very site specific and difficult to summarise on a “whole site” basis. The decision was made to put all soils data into the report (with the raw data in appendices) and produce simple summary tables which enabled the reader to assess the implications of soil data at a glance.

A simple classification approach was adopted for the soils data that uses a three colour system to highlight findings that are of concern for assessing for suitability for use of the land for agricultural production and for environmental risk.

This approach is only used for the analytical results as more subjective findings cannot be easily classified using this approach. Only plant-available nutrients (i.e. extractable nutrients) in the mineral fraction have been considered, since it is not possible to determine the plant-availability of nutrients from deeply buried organic layers.

The assessment of organic matter levels within the soil profile is done with the presumption that the restoration program is a controlled process that can be managed to achieve set outcomes. At study Site 1 and 2 the method statements stated that operational depths (depth of sewage sludge incorporation) would not exceed a maximum of 200 and 400 mm respectively. The acceptance of a 400 mm incorporation depth is not justifiable. Functioning topsoil depth is restricted to 300 mm and there are no ecological, forestry or agricultural outcomes that can justify the incorporation of wastes such as sewage sludge to depths greater than 300 mm.

The continued presence of organic matter in the lower parts of soil profiles (below 300 mm) is therefore deemed as poor restoration practice, a potential environmental risk and will reduce the suitability of the land for agriculture as it raises concerns about subsistence, increased risk of compaction and a reduction in drainage capacity. Due to the acceptance by SEPA of 400 mm as a suitable incorporation depth under the terms of WME licences the criteria used in this assessment for maximum acceptable incorporation is however 400 mm.

Tables 5.6.1 and 5.6.2 outline the definitions used for the three colour classification.

Table 5.6.1. Assessment of suitability for agriculture

Colour coding	Classification descriptor
Green	Indicator of suitability for agriculture: Green was used to highlight results that represented soil conditions suitable for agricultural production or when there was *no specific impact for agriculture*. Specific criteria included: • Plant-available P and K status moderate (M –) or higher in upper profiles and low (L) or very low (VL) in any underlying layer (below 300 mm) based on SAC methods. • Plant-available Mg at a moderate (M) or higher status in the upper profiles based on SAC methods. Plant available Mg level in lower layers is not considered as it can be naturally occurring. • pH > 5.5 in upper parts of soil profile, based on SAC methods, as this the minimum limit needed for efficient production and to justify the application of nutrients. • Organic content ≥ 5% in upper parts of the soil profile (400 mm). An organic content level of 5% is a minimum limit for clay soils if they are to be considered topsoil. • Organic content <5% in the lower parts of the soil profile
Yellow	Indicator of concern for agriculture: Yellow was used to highlight results that had a potential impact on agriculture production or when results are outside appropriate ranges given the restoration methods used. Specific criteria included: • Plant available P and K status is low in the upper layer based on SAC methods. • Plant-available P and K status in lower mineral layers at or above M based on SAC methods. This would be indicative of the burial of nutrients that are out of reach of plant roots. • SOM < 5% in the upper parts of soil profile and ≥ 5% and ≤ 15% in lower parts. Organic content in topsoil's below 5% would be a concern as it will impact the tilth of the soil and its ability to regulate nutrients. Buried organic matter is a concern for agriculture as it can impede drainage and leave land vulnerable to compaction and subsidence.
Red	Indicator of soil conditions unsuited for agriculture: Red was used to highlights results that would have a direct impact on agricultural production. Specific criteria included: • Very Low plant-available P and K status in upper mineral layer based on SAC methods • Organic content in lower parts of soil profile > 15%. Buried organic matter is a concern for agriculture as it can impede drainage and leave land vulnerable to compaction and subsidence. • pH ≤ 5.5 or less in upper parts of soil profile based on SAC methods.

Table 5.6.2. Assessment of environmental risk

Colour coding	Classification descriptor
Green	Indicator of low environmental risk: Green was used to highlight results that represented no obvious concern for the environment. Specific criteria included: • Organic content in lower parts of soil profile < 5%. • Plant-available P status in lower mineral layers is low or very low based on SAC methods. • pH ≥ 5 in the upper layer, based on SAC method
Yellow	Indicator of concern for environmental risk: Yellow is used to highlight results that represented a potential risk to the environment. Specific criteria included: • Plant-available P status of M in lower mineral layers based on SAC methods. • Organic content ≥ 5% and ≤ 15% in lower parts of soil profile. The burial of SS or organic material poses a potential risk to groundwater quality.
Red	Indicator of environmental risk: Red was used to highlight results that indicated a clear potential risk to the environment. Specific criteria included: • Plant-available P status of H or higher in lower mineral layers based on SAC methods. This is a concern to potential leaching to ground water. • Organic content > 15% in lower soil profiles which is indicative of buried organic layer and a higher risk of nutrient loss to ground water. • pH below 5 in the upper layer, based on SAC methods, which is a concern due the potential risk of PTE leaching

6 Site 1

6.1 Broad site description and restoration practice

Mining operations ceased altogether in 2005 but restoration of parts of the site had already begun before that date. Although the original intention was apparently to restore the site to a mixture of agricultural grazing, broadleaved woodland, commercial forestry (conifers) and amenity land with paths for public access, the initial site survey quickly showed that much of the site had been inadequately re-shaped, with many areas of steep, heavily compacted ground, ponds and wet areas present. There were no fences to contain livestock. There was also a lot of bulky inorganic waste/rubbish on parts of the site (tyres, broken glass, old mattresses, lumps of concrete and bricks/rubble). Aggressive weed species were dominant on many of the "restored" areas rather than desirable agricultural, forestry or amenity species. There were extensive areas of apparently unrestored land, much of which had a heavily compacted surface. This type of land was often quite species-rich, and contained a range of orchids and other attractive wildflower species.

Although records of the restoration practices used are incomplete, the general intention was to use sewage sludge at rates of between 200 and 400 t/ha to "improve" soils on the site.

6.2 Initial site survey

The site was visited on 1st June 2017 and a thorough inspection was made of the site (with brief soils investigations) with a view to choosing six areas for detailed study. It was also very difficult to walk on the site. Vegetation in many areas was deep and tangled, and the ground surface was extremely rough in places, with frequent water-filled holes, steep ground, lumps of rock and concrete.

It was clear in some instances, that where a WMLE had been lodged with the intention of applying a particular amount of sludge over a specified area, this had not always been done evenly in accordance with the description in the WMLE. For example, vegetation analysis and soil investigations at Site 1 suggested that steep slopes within specified areas had not been spread with sludge at all, but the flat and more gently sloping areas had. It was not clear during the initial site visit (or from any written records) whether much lower total amounts had in the end been spread (than the total stated in the WMLE), or whether the full amounts stated on the WMLE had been applied over much smaller areas than stated (leading to much higher tonnages being applied per unit area than stated). Six areas were chosen for further study based on the fact that together they represented a good cross section of previous restoration practice on the site and also that at least some information was obtained on what should have been done during restoration. Details of the initial site survey are recorded in Appendix 1.

The six study areas and the restoration practices which were registered with SEPA are briefly described in Section 6.3.

6.3 Description of six individual study areas

Area 1 (50 ha). This area was located in the northeast of the site. Although it had apparently been restored, it was rough, uneven and full of holes and ditches. It also contained many rocks and large blocks of concrete, which were well hidden in deep vegetation. For this reason, it would not be safe for the public to walk on (at least in late Spring and Summer) or for livestock grazing without a certain amount of levelling and removal of the large rocks and concrete blocks. It also would need to be fenced if livestock were to be introduced. Area 1 was restored using sewage sludge as shown in Table 6.1.3 between October 2012 and March 2014.

Table 6.3.1. Restoration practice in Area 1	
Total amount requested under this exemption	20,000 tonnes of sewage sludge (and 9,000 tonnes in the renewal), actual amount applied not known, since no waste data return was available.
Application rate	200-450 t/ha ("depending on the sludge", according to exemption); average may have been around 400 t/ha if the intended 20,000 tonnes were applied to all 50 ha (based on the size of the area and the total amount to be used). However, evidence suggests that not all of this area had sludge applied. If all 20,000 tonnes were applied to a smaller area within that covered by the WMLE, then a much higher rate may have been applied in places (up to 900 t/ha?).
Application method	Trenches (4 m wide, 20 cm deep) filled with sewage sludge and covered by substrate from next trench. Incorporation depth to 40 or 50 cm was permitted for trees.
Restored area	22 ha (of a total of 50 ha) in first application and 28 ha in the second (renewal) application.
Habitats to be established	Grassland, scrub and trees to provide habitat for winter-feeding waterfowl and ground-nesting birds; grassland could provide grazing for sheep.

Area 2 (exact area unknown, although it could potentially be 50 ha). The area marked on maps compiled by SEPA regulatory staff looks smaller, perhaps about 25 ha). The study area is fairly flat, but although it had apparently been restored, it was rough, uneven and full of holes and ditches. It also contained many rocks and large blocks of concrete, which were well hidden in deep vegetation. For this reason, it would not be safe for the public to walk on (at least in late Spring and Summer) or for livestock grazing without a certain amount of levelling and removal of the large rocks and concrete blocks. It also would need to be fenced if livestock were to be introduced. Area 2 has been restored using sewage sludge as shown in Table 6.3.2 between May 2011 and April 2012.

Table 6.3.2. Restoration practice in Area 2	
Total amount requested/spread under this exemption	20,000 tonnes of sewage sludge requested and 19,865 applied (according to waste data return).
Application rate	No WMLE, Cert. of Ag. Benefit or waste data returns available. If the intended 20,000 tonnes were applied to 50 ha, then the application rate will have been 400 t/ha. However, the full 20,000 tonnes may have been spread on a smaller area; therefore much higher rates may have been applied in places.
Application method	No information.
Restored area	Not known, but likely to have been up to 50 ha.
Habitats to be established	Not known.

Area 3 (78 ha). This study area was situated in the northwest of the site. It was fairly flat and had damp patches in it, but no standing water. Although this area had apparently been restored, it was rough, uneven and had a few holes and ditches. It contained fewer rocks and blocks of concrete than Areas 1, 2 and 5. Due to the dense, high vegetation and the presence of holes and ditches, it would not be safe for the public to walk on (at least in late Spring and Summer) or for livestock grazing without a certain amount of levelling and removal of the large rocks and concrete blocks. It also would need to be fenced if livestock were to be put on the land. Area 3 has been restored using sewage sludge as shown in Table 6.3.3 from March 2013.

Table 6.3.3. Restoration practice in Area 3	
Total amount requested/spread under this exemption	30,000 tonnes of sewage sludge (and 8,200 tonnes in the renewal). Actual amount applied not known, since no waste data return was available.
Application rate	200-400 t/ha (apparently depending on the sludge); but if all 38,200 was applied then the average would have been 490 t/ha.
Application method	Trenches (4 m wide, 20 cm deep) filled with sludge and covered by substrate from next trench. An alternative method (sludge surface spread and incorporated) was mentioned in the renewal but it is not known whether this happened.
Restored area	78 ha
Habitats to be established	Grassland, scrub and trees to provide habitat for winter-feeding waterfowl and ground-nesting birds; grassland could provide grazing for sheep.

Area 4 (50 ha). This area was situated in the north west of the site. It contained flat or gently sloping land, which faced southwest. It had a few water-filled ditches but was dry underfoot during the main site visits. The soil surface was relatively even (in comparison to other study areas walked) and it contained very few rocks and rubbish. Due to the dense, high vegetation present in much of the area, it would not be practical for the public to walk on the main area of restored land here (at least in late Spring and Summer) and there were few useful plants on which livestock could graze. It also would need to be fenced if livestock were to be introduced. Area 4 has been restored using sewage sludge as shown in Table 6.3.4 between April 2012 and March 2014.

Table 6.3.4. Restoration practice in Area 4	
Total amount requested/spread under this exemption	20,000 tonnes of sewage sludge requested and 17,972 applied. A further 20,000 tonnes was requested in the renewal, but no record exists of whether this happened.
Application rate	200-400 t/ha was requested (apparently depending on the sludge); but if initial 20,000 t was applied to 26 ha (as waste data return for the first WMLE suggests) then an average rate of 691 t/ha must have been applied (if it had not disappeared underground from storage pits). In the renewal, if 20,000 t was applied to 24 ha as requested, then a mean rate of 833 t/ha must have been used (but there is no waste data return for the renewal).
Application method	Trenches (4 m wide, 20 cm deep) filled with sludge and covered by substrate from next trench.
Restored area	50 ha
Habitats to be established	Grassland, scrub and trees to provide habitat for winter-feeding waterfowl and ground-nesting birds; grassland could provide grazing for sheep.

Area 5 (50 ha). This was located in the east of the site, close to Area 1. It was generally flat, but there was a small, constructed mound towards the southeast of the area. Although this area had apparently been restored, it was rough, uneven and full of holes and ditches. It also contained many rocks and large blocks of concrete, which were well hidden in deep vegetation. For this reason, it would not be safe for the public to walk on (at least in late Spring and Summer) or for livestock grazing without a certain amount of levelling and removal of the large rocks and concrete blocks. It also would need to be fenced if livestock were to be introduced. Area 5 has been restored using sewage sludge. Limited details were found on how this has been restored. It is thought that it was restored under the same WMLE as for Area 1.

Area 6 (50 ha). This was the most northerly of the six study areas chosen. The area was gently south-facing and reasonably dry underfoot during our visits, although there were some wet patches at the bottom of the slope to the south of the area. The area was uneven and rough in places, although it contained fewer rocks and blocks of concrete than Areas 1, 2 and 5. Due to the dense, high vegetation and presence of hidden holes and ditches, it would not be safe for the public to walk on or for livestock grazing without a certain amount of levelling. It would also require to be fenced if livestock were to be put on the land. Area 6 has not had a WMLE registered on it and has not been restored, although there is evidence that the area has been land-formed (in that the soil surface is reasonably smooth, with no cliffs or holes).

6.4 Soil assessment and analysis

The results of the soil profile assessments and a summary of the soil analysis data are provided in the following sections. Photographs of the soil pits are shown in Appendix 3 (Photographs of soil pits) and the PDFs of full laboratory analysis data are presented in Appendix 4 (Soil and sludge analysis: full results).

6.4.1 Site 1, Area 1

6.4.1.1 Overview

The topsoil was a heavy textured clay loam to between 180 and 300 mm (Layer 1) overlaying a similar but distinct subsoil (Layer 2) to a combined depth of between 320 and 600 mm. The boundary between the two layers was clear and irregular. There was evidence of soil formation processes in Layer 1, as shown by structure and colour changes. Below Layer 2 there was an unincorporated layer of sewage sludge (sludge) that had an average thickness of 190 mm but this varied considerably. The boundary layer between Layer 2 and the sludge was abrupt and smooth.

The sludge layer was continues but varied in thickness from 50 – 190 mm and in places occurred as a series of buried “balls” (see photograph in Appendix 3). There was little evidence of mixing with the soil around it and the sludge had a distinct smell and texture. There was a drainage restriction at the base of the sludge layer and the sludge was saturated. The pit walls began to collapse as the sludge layer began to flow following excavation.

6.4.1.2 Profile description

Table 6.4.1 summarises the soil profile. The presence of the sludge and the collapsing of the soil pit meant that there was only a limited time for measurements and photographs.

6.4.1.3 Analytical results

Four samples were collected: one from the upper layer (Layer 1), one from Layer 2, one from the sewage sludge layer (Layer 3) and an additional one from the underlying overburden (Layer 4).

The organic matter content in each of the mineral layers was similar based on LOI and ranged from 5.8 – 6.5% (Table 6.4.2). The calculated Dumas results were different, with Layer 1 having an organic content of 9.4%. Layer 2 was 6.9% and Layer 4 was 5.4%. The sludge layer (Layer 3) had a high organic content of 40% based on LOI. The occurrence of Layer 3, which appeared to be made up largely of sludge with a high organic content, at a starting depth of 600 mm has been classed as being of environmental concern, as it poses a potential risk to groundwater (Table 6.4.2). It was also classed as concern for agriculture since it occurred below the rooting depth of most target plant species and its eventual loss through anaerobic decomposition will cause localised slumping and drainage restrictions. Its occurrence as a distinct layer at such a depth was also deemed to represent a poor restoration outcome.

Table 6.4.1. Profile description for Site 1, Area 1

Site 1, Area 1			
Layer	1.1	1.2	1.3 (Sewage sludge)
Thickness (mm)	180 - 300	140 - 300	190
Texture	CL	CL	
Colour	2YR 4/0	2YR 5/0	
Average bulk density (g/cm^3)	1.48	1.53	
Ped shape	medium platy	massive	
Ped grade	moderate	apedal - massive	
Ped Strength	moderately strong	very strong	
% pores	2	0.5	
Boundary form from upper profile		irregular	smooth
Boundary distinctness from upper profile		clear	abrupt
Stone Size (mm)	10 - > 150	10 - > 300	
Stone Abundance (%)	20	30	
Soil Water state	wet	wet	
Max root depth (mm)	320		
Root abundance	common	few	
Smell	no smell	no smell	strong sludge smell
Earthworm numbers	5		
Fungal hyphae	common		
Ped size (mm)	30 - 40	massive	
VESS/SubVESS	Sq4	Ssq4	
Depth to Water Table	Not encountered		

Table 6.4.2. Organic content of mineral and organic layers

Site 1, Area 1				
	LOI (%)	Organic matter (%) (Dumas - calculated)	Suitability for agriculture	Environmental concern
Layer 1 upper (0 - 300 mm)	6.5	9.4		
Layer 2 (300 - 600 mm)	6	6.9		
Layer 3: SS layer (600 - 790 mm)	40.3	39.5		
Layer 4 (below SS layer (790 - > 900 mm)	5.8	5.4		

Organic matter levels above 3% in the mineral fraction (Layer 4) at a depth below 300 mm in the profile has also been highlighted as being of possible environmental concern and as an indicator of poor restoration outcome.

The available plant nutrient levels were very similar in each mineral layer, with each being very low in P, moderate for K and very high in Mg (based on SAC methods, Table 6.4.3). The ADAS results were similar to those obtained using the SAC methods.

Table 6.4.3. Plant-available nutrients and pH of the mineral fractions

Site 1, Area 1					
		SAC	ADAS	Suitability for agriculture	Environmental concern
Layer 1 upper (0 - 300 mm)	Available P (mg/l)	1.4(VL)	2.5(0)		
	Available K (mg/l)	131(M-)	116(1)		NA
	Available Mg (mg/l)	610(H)	333(5)		NA
	pH	7.2	7.9		
Layer 2 (300 - 600 mm)	Available P (mg/l)	1.5(VL)	5.2(0)		
	Available K (mg/l)	164(M-)	152(2-)		NA
	Available Mg (mg/l)	637(H)	467(6)	NA	NA
	pH	7.1	7.1		
Layer 4 (below SS layer (790 -> 900 mm)	Available P (mg/l)	1.5(VL)	4.8(0)		
	Available K (mg/l)	129(M-)	114(1)		NA
	Available Mg (mg/l)	433(H)	304(5)	NA	NA
	pH	6.4	7		

NA = Not applicable

The deficiency in P in the upper layer (Layer 1) was highlighted as concern for agriculture. Since sewage sludge is typically a good source of P, its absence in the rooting zone following restoration was deemed a poor restoration outcome. The occurrence of meaningful amounts of plant-available K at depths below 300 mm was also highlighted as a poor restoration outcome.

Heavy metal concentrations in the mineral fractions (Layers 1, 2 and 4) were low, normal or of no specific concern and the pH of all three layers was alkaline based on ADAS methods. The results obtained using the SAC methods were similar, apart from for Layer 4, which was found to be moderately acidic.

The analysis of the sludge layer from Site 1, Area 1 is provided in Appendix 4. The results were typical for a stabilised cake aside from the available N content, which was slightly higher than typical and the total P content which was lower than commonly used reference values. The heavy metal concentrations were typical for sludge.

6.4.2 Site 1, Area 2

The soil had a heavy textured clay upper layer (Layer 1) to between 120 and 280 mm, overlaying either a sandy clay loam (Layer 2) or a layer of sewage sludge (Layer 3). Where present, Layer 2 varied in thickness from 0 – 320 mm and there was a clear boundary distinction between it and the upper and lower layers. Where present, the sewage sludge layer varied in thickness from 220 – 280 mm. The presence of sludge was not consistent within the pit, but occurred as buried “balls” (See photograph in Appendix 3) across the face of the pit. The sludge overlaid a heavy textured boulder clay to a depth of > 700 mm.

There are clear indications of topsoil development in the upper 120 mm, as evidenced by colour and structural changes. There was a drainage restriction at ~ 320 mm and soils (or sludge) at this junction were at or above their plastic limit.

6.4.2.1 Profile description

Table 6.4.4 summarises the soil profile. The presence of the sludge, drainage restrictions and the heavy texture of the underlying materials meant that there was only a limited time for measurements and photographs. It was necessary to excavate at two separate pits within Area 2, so that sufficient pictures and measurements could be taken before the pits filled with water and sludge.

Table 6.4.4. Profile description for Site 1, Area 2

Site 1, Area 2			
Layer	1	2	Sludge
Thickness (mm)	120 - 280	variable (0 - 320)	220 – 280 (intermittent)
Texture	CL	SCL	
Colour	2.5Y 4/2	2.5Y 5/0	
Average bulk density (g/cm^3)	1.24	1.41	
Ped shape	medium platy	coarse blocky	
Ped grade	moderately developed	weakly developed	
Ped strength	moderately firm	very firm	
% pores	5	2	
Boundary form from upper profile		broken	broken
Boundary distinctness from upper profile		clear	clear
Stone size (mm)	10 -70	2 – 70	
Stone abundance (%)	20	20	
Soil water state	wet	wet	
Max root depth (mm)	220		
Root abundance	common (medium)	few (fine)	
Smell	no smell	no smell	strong sludge smell
Earthworm numbers	6		
Fungal hyphae	common		
Ped size (mm)	20 – 40		
VESS/SubVESS	Sq4	Ssq4	
Depth to Water Table	Not encountered		

6.4.2.2 Analytical results

Three samples were collected: one from the Layer 1, one from Layer 2 and a third from the sewage sludge layer (Layer 3). The organic content in the upper layer (Layer 1) was moderate at 8.3% and much lower in (3.3%) in Layer 2 (Table 6.4.5). The sludge layer had a very high organic content of 53% based on LOI.

The occurrence of an organic layer at depths below 300 mm was deemed an environmental concern due to potential risks to groundwater and was deemed unsuitable for agriculture as it is below the topsoil depth and typical rooting potential for most plant species. Its presence was also an indicator of a poor restoration outcome.

The nutrient content in both mineral fractions was similar, with P being low or very low/index 0, K moderate/index 1 or 2 and Mg high/index 4 or 5 (Table 6.4.6). The pH differed between layers however, with the upper layer (Layer 1) having a low pH of 5.5 and Layer 2 having a slightly acidic pH of 6.7 based on ADAS methods. The pH

Table 6.4.5. Organic content of mineral and organic layers

Site 1, Area 2				
	LOI (%)	Organic matter (%) (Dumas - calculated)	Suitability for agriculture	Environmental concern
Layer 1: upper (0 - 300 mm)	8.3	7.9		
Layer 2: broken layer (300 - 540 mm)	3.3	3.3		
Layer 3: broken SS layer (300 - 500 mm)	53	50.3		

Table 6.4.6. Plant-available nutrients and pH of the mineral fractions

Site 1, Area 2					
		SAC	ADAS	Suitability for agriculture	Environmental concern
Layer 1: upper 0 - 300 mm)	Available P (mg/l)	1.8(L)	8.8(0)		
	Available K (mg/l)	133(M-)	114(1)		NA
	Available Mg (mg/l)	243(H)	197(4)		NA
	pH	4.4	5.5		
Layer 2: broken layer (300 - 540 mm)	Available P (mg/l)	1.5(VL)	3.4(0)		
	Available K (mg/l)	169(M+)	150(2-)		NA
	Available Mg (mg/l)	516(H)	342(5)	NA	NA
	pH	6.3	6.7		

NA = Not applicable

obtained using a CaCl extractant showed a strongly acidic pH (4.4) in Layer 1, but in Layer 2, soil pH was similar with both methods.

The P deficiency in Layer 1 is deemed a concern for agriculture as is the low pH. The low P status of the upper profile and the occurrence of agriculturally meaningful amounts of K at depths below 300 mm are also highlighted as an indicator of poor restoration outcomes. The pH of the Layer 1 is also highlighted as a possible concern for restoration outcomes as it contrasts sharply with the pH of lower layers and is low enough to bring into question the suitability of using sewage sludge on this land.

Heavy metal concentrations in the mineral fractions (Layers 1, 2 and 4) were low, normal or of no specific concern. Analysis showed that the sludge was typical for a stabilised cake, aside from its total P content which was lower than commonly used reference values (Appendix 4). The heavy metal concentrations were typical for sewage sludge.

6.4.3 Site 1, Area 3

The soil was a heavy textured sandy clay (Layer 1) to between 110 – 140 mm overlying a heavy textured sandy clay layer (Layer 2) that varied in thickness from 150 – 210 mm, depending on the presence of a sewage sludge layer. The sludge layer was between 80 – 250 mm thick, but it did not occur consistently as a layer of defined thickness. There was a buried "ball" (See Photographs in Appendix 3) of sludge" with a maximum diameter of 250mm. Below this was a heavy textured clay subsoil with a high stone content.

6.4.3.1 Profile description

Table 6.4.7 summarises the soil profile. The presence of sewage sludge meant that only a limited amount of time could be spent in the pit for health and safety concerns. In addition the sludge was at its plastic limit and the pit collapsed shortly after excavation.

Table 6.4.7. Profile description for Site 1, Area 3

Site 1, Area 3				
Layer	1	2	3 (sewage sludge)	4
Thickness (mm)	100 - 140	150 - 210	80 – 250	to depth
Texture	SCL	clay		clay
Colour	10YR 6/6	10yr 6/7		5Y 5/1
Average bulk density (g/cm^3)	1.44	1.49		
Ped shape	coarse blocky	massive		massive
Ped grade	massive	massive		
Ped Strength	course angular blocky	massive		massive
% pores	0.5	0.1		0.1
Boundary form from upper profile		broken	broken	broken
Boundary distinctness from upper profile		clear	clear	clear
Stone size (mm)	10 - 150	30 - 150		30 - > 500
Stone abundance (%)	10	35		40%
Soil water state	wet	wet		wet
Max root depth (mm)	220			
Root abundance	common	few		
Smell	no smell	no smell	strong sludge smell	sludge smell
Earthworm numbers	0			
Fungal hyphae	none			
Ped size (mm)	30	massive		massive
VESS/SubVESS	Sq5	Ssq5		Ssq5
Depth to Water Table	Not encountered			

6.4.3.2 Analytical results

Three samples were collected, one from the upper Layer (Layer 1), a second from Layer 2 and the third from the sewage sludge layer (Layer 3).

Based on LOI, the organic content in upper layer (Layer 1) was low at 4.8% (Table 6.4.8). It was higher (5.6%) in Layer 2 and highest (65%) in the sewage sludge layer (Layer 3).

The organic content in Layer 1 was below 5% and was highlighted as a concern for agriculture. The presence of an organic layer starting at ~ 390 mm was also highlighted due to risk of localised slumping and because it occurred below typical rooting depths and would not be acting as a source of plant nutrients.

Table 6.4.8. Organic content of mineral and organic layers

Site 1, Area 3				
	LOI (%)	Organic matter (%) (Dumas - calculated)	Suitability for agriculture	Environmental Concern
Layer 1: upper (0 - 140 mm)	4.8	4.3		
Layer 2 (140 - 390 mm)	5.6	5.1		
Layer 3: SS layer (390 - 640 mm)	65.4	35.9		

The low organic content in Layer 1 was a concern for restoration outcomes as, is the increase in organic content with depth. It was also noted at this and other areas that no roots occurred within the sewage sludge layer. This may be in part due to the depth of the sludge layer but may also be the result of phytotoxic conditions arising from the presence of a concentrated sludge layer with high salt levels and little oxygen.

Layer 1 had very low/index 0 available P, moderate/index 1 K and high/index 4 Mg levels (Table 6.4.9). Layer 2 was also very low in P (index 0) but had high levels of both K and Mg (K was index 2+). The pH differed between layers, with Layer 1 having a low pH of 5.3 and Layer 2 an alkaline pH of 7.6 based on ADAS methods. The pH obtained with a CaCl extraction in Layer 1 was strongly acidic (4.8) but a similar results were obtained in Layer 2 with both methods.

Table 6.4.9. Plant-available nutrients and pH of the mineral fractions

Site 1, Area 3					
		SAC	ADAS	Suitability for agriculture	Environmental concern
Layer 1: upper (0 - 140 mm)	Available P (mg/l)	1.4(VL)	5(0)		
	Available K (mg/l)	91(M-)	87.4(1)		NA
	Available Mg (mg/l)	294(H)	244(4)		NA
	pH	4.8	5.3		
Layer 2: (140 - 390 mm)	Available P (mg/l)	1.4(VL)	2.5(0)		
	Available K (mg/l)	235(H)	220(2+)		NA
	Available Mg (mg/l)	545(H)	416(6)	NA	NA
	pH	7.1	7.6		

NA = Not applicable

The very low levels of plant-available P in Layer 1 were a concern for agriculture and were classed as a poor restoration outcome. The low pH in Layer 1 was a concern for agriculture and for restoration success, since it contrasted with the alkaline nature of the underlying mineral fraction.

Heavy metal concentrations in the mineral fractions (Layers 1 and 2) were low, normal or of no specific concern. Analysis showed that the sludge was typical for a stabilised cake, aside from its total P content which was lower and its available N content, which was higher than commonly used reference values (Appendix 4). The heavy metal concentrations were typical for sewage sludge.

6.4.4 Site 1, Area 4

The soil was a medium textured sandy clay soil to 350 mm (Layer 1) overlying a 180 to 220 mm thick deposit of sewage sludge (Layer 2). Under this is a heavy textured boulder clay (Layer 3) with a very high stone content to > 700 mm. The soil profile was consistent, with clear boundaries between layers.

Layer 1 was a developed topsoil with good rooting potential and a coarse, blocky structure. Worms were plentiful, and there was moderately good drainage to 300 mm where compaction increased directly above the sewage sludge layer.

6.4.4.1 Profile description

Table 6.4.10 summarises the soil profile. There was a clear indication of soil structural improvement in Layer 1 when contrasted with Layer 3

Table 6.4.10. Profile description for Site 1, Area 4

Site 1, Area 4			
Layer	1	2 Sewage sludge	3
Thickness (mm)	350	180 - 220	to depth
Texture	CL		clay
Colour	7YR 5/2		7YR 5/0
Average bulk density (g/cm^3)	1.47		1.68
Ped shape	medium blocky		course blocky
Ped grade	moderately developed		massive
Ped Strength	firm		very firm
% pores	15% fine to medium		0.5 fine
Boundary form from upper profile		Smooth	smooth
Boundary distinctness from upper profile		Clear	abrupt
Stone size (mm)	20 – 50		> 50
Stone abundance (%)	15		50
Soil water state	moist		wet
Max root depth (mm)	280 - 320		NA
Root abundance	common		NA
Smell	no smell	strong sludge smell	sludge smell
Earthworm numbers	9		
Fungal hyphae	common		
Ped size (mm)	20		Massive
VESS/SubVESS	Sq3		Ssq5
Depth to Water Table	Not encountered		

6.4.4.2 Analytical results

Three samples were collected, one from the upper layer (Layer 1), a second from Layer 3 (below the sludge layer) and a third from the sewage sludge layer (Layer 2).

The organic content in the upper layer (Layer 1) was moderate at 6.9% and lower (4.4%) in Layer 3 based on LOI (Table 6.4.11). The calculated organic content gave similar but slightly higher organic contents in both layers. The sewage sludge layer (Layer 2) had a very high organic content of 48% based on LOI.

Table 6.4.11. Organic content of mineral and organic layers

Site 1, Area 4				
	LOI (%)	Organic matter (%) (Dumas - calculated)	Suitability for agriculture	Environmental concern
Layer 1: upper (0 - 350 mm)	6.9	7.3		
Layer 2: SS layer (350 - 570 mm)	48.1	43.9		
Layer 3: Below SS layer (570 > 700 mm)	4	5		

The occurrence of a distinct organic sewage sludge layer at a depth below 300 mm was highlighted as being unsuitable for agriculture, as it will restrict drainage, inhibit root growth and will result in localised slumping. It also posed as a potential environmental risk to groundwater quality and was deemed a poor restoration outcome. The relatively high organic content in the mineral layer below the sludge layer was also deemed a concern for restoration success.

The two methods used for plant-available nutrient content found differing results for Layer 1 (Table 6.4.12). The SAC method showed that available P was low, whereas the ADAS analysis showed it to be index 3 (roughly equivalent to high on the SAC scale). For the upper layer (Layer 1), both methods showed the K levels to be moderate/index 2 and the Mg level high/index 5. The available nutrient results for Layer 3 were similar for both methods with P levels being very low/index 0, moderate/index 2- for K and high/index 5 for Mg.

Table 6.4.12. Plant-available nutrients and pH of the mineral fractions

Site 1, Area 4					
		SAC	ADAS	Suitability for agriculture	Environmental concern
Layer 1: upper (0 - 350 mm)	Available P (mg/l)	3(L)	30.4(3)		
	Available K (mg/l)	173(M+)	150(2-)		NA
	Available Mg (mg/l)	355(H)	266(5)		NA
	pH	4.6	5.5		
Layer 3: below SS layer (570 > 700 mm)	Available P (mg/l)	1.4(VL)	4.4(0)		
	Available K (mg/l)	146(M+)	137(2-)		NA
	Available Mg (mg/l)	444(H)	308(5)	NA	NA
	pH	7.2	7.4		

NA = Not Applicable

Based on ADAS methods the pH of the upper horizon was found to be acidic at 5.5, but when a CaCl approach extractant was used, the pH was strongly acidic (4.6). Both test methods found that Layer 3 was moderately alkaline.

The low pH of the upper profile was highlighted as a concern both for agriculture and in terms of restoration success as it contrasts with the pH of lower mineral fractions and was low enough to suggest that sewage sludge should not have been used for restoration purposes on this land.

Heavy metal concentrations in the mineral fractions (Layers 1 and 3) were low, normal or of no specific concern. Analysis showed that the sludge was typical for a stabilised cake, aside from its total P content which was lower than commonly used reference values (Appendix 4). The heavy metal concentrations were typical for sewage sludge.

6.4.5 Site 1, Area 5

The soil was a heavy textured clay loam upper layer (Layer 1) to 220 mm over a mineral clay loam layer (Layer 2) that varied in depth between 140 and 370 mm. This overlaid a distinct layer of sewage sludge (Layer 3) that varied in thickness between 40 mm and 240 mm. The sludge layer was not continuous and appeared to be a buried "ball" (See Photographs in Appendix 3) of sludge that was partially smeared onto the lower mineral layer (Layer 4) prior to being buried. This overlaid a heavy textured clay subsoil (layer 4) to depth.

The upper soil to 220 showed signs of topsoil development that were reflected in colour modification and structural changes. There has been significant root penetration to 500 mm when sewage sludge was not present and worms were common. When sewage sludge occurred within the top 500 mm of the profile, it was noted that plant roots could not get into or past it. No worms were found in the sludge. Drainage was restricted just below the sludge layer due to compaction.

6.4.5.1 Profile description

Table 6.4.13 summarises the soil profile.

Table 6.4.13. Profile description for Site 1, Area 5

Site 1, Area 5				
Layer	1	2	3 Sewage Sludge	4
Thickness (mm)	220	140 - 370	40 – 240	To depth
Texture	CL	CL		clay
Colour	7.5 YR 6/2	7.5 YR 7/2		7.5 YR 7/2
Average bulk density (g/cm³)	1.38	1.51		
Ped shape	medium platy	coarse platy		course platy
Ped grade	moderately developed	apedal massive		apedal Massive
Ped strength	moderately firm	strong		strong
% pores	5 – 10	0.5		0.1
Boundary form from upper profile		irregular	wavy	wavy
Boundary distinctness from upper profile		clear	broken	broken
Stone size (mm)	2 – 50	10 – 50		10 - >700
Stone abundance (%)	20	30		4500%
Soil water state	wet	moist		moist
Max root depth (mm)	500			
Root abundance	common			
Smell	no smell	no smell	strong sludge smell	sludge smell
Earthworm numbers	6			
Fungal hyphae	few			
Ped size (mm)	20 – 50	massive		massive
VESS/SubVESS	Sq4	Ssq5		Ssq5
Depth to Water Table	Not encountered			

6.4.5.2 Analytical results

Three samples were collected: one from the upper layer (Layer 1), one from Layer 2 and one from the sewage sludge layer (Layer 3).

Based on LOI, the organic content in the upper horizon was moderate at 6.1%, but the calculated organic content based on the DUMAS method was higher at 7.8% (Table 6.4.14). Both methods found that Layer 2 had a moderate organic content (5.8% and 6.4% for the LOI and DUMAS methods respectively). The sewage sludge had a high organic content of 51% based on LOI.

Table 6.4.14. Organic content of mineral and organic layers

Site 1, Area 5				
	LOI (%)	Organic matter (%) (Dumas - calculated)	Suitability for Agriculture	Environmental Concern
Layer 1: upper (0 - 220 mm)	6.1	7.8		
Layer 2: (220 - 590 mm)	5.8	6.4		
Layer 3: SS layer (590 - > 700)	51.2	40.3		

The occurrence of the highly organic sewage sludge layer below 300 mm was deemed unsuitable for agriculture as it would impact on the potential of the soil to drain, would result in localised slumping and would impact on rooting depth. It was noted that no roots were growing into or past the sludge layer. The presence of the sludge layer was also classed as an indicator of poor restoration success.

Both methods used to determine soil nutrient status showed similar results for Layers 1 and 2, with P being very low/index 0, K moderate/index 1 and Mg high/index 5 or 6 (Table 6.4.15).

Table 6.4.15. Plant-available nutrients and pH of the mineral fractions

Site 1, Area 5					
		SAC	ADAS	Suitability for agriculture	Environmental concern
Layer 1: upper (0 - 220 mm)	Available P (mg/l)	1.4(VL)	2.5(0)		
	Available K (mg/l)	115(M-)	112(1)		NA
	Available Mg (mg/l)	586(H)	330(5)		NA
	pH	7.3	8.0		
Layer 2: (220 - 590 mm)	Available P (mg/l)	1.5(VL)	3.8(0)		
	Available K (mg/l)	91(M-)	110(1)		NA
	Available Mg (mg/l)	599(H)	417(6)	NA	NA
	pH	7.2	7.9		

NA = Not applicable

Based on ADAS methods, the pH of Layer 1 was strongly alkaline, with a pH of 8. Results using a CaCl extraction also found this layer to be alkaline, but with a lower pH of 7.3.The lower mineral layer (Layer 2) was also alkaline, with the ADAS method showing a pH of 7.9 and the CaCl method a pH of 7.2.

The very low level of plant-available P in the upper layers was classed as both a concern for agriculture and an indicator of a poor restoration outcome.

Heavy metal concentrations in the mineral fractions (Layers 1 and 2) were low, normal or of no specific concern. Analysis showed that the sludge in Layer 3 was typical for a stabilised cake, aside from its total P content which was lower than commonly used reference values and its total N content, which was higher (Appendix 4). The heavy metal concentrations were typical for sewage sludge.

6.4.6 Site 1, Area 6

This pit was excavated in an attempt to provide a control area, where no sewage sludge had been incorporated. This was only partially successful as those areas across the site which did not receive treatment were either used for roadways or are stone pits. This pit was dug directly adjacent to a road cutting through the site. It was selected because it was partially vegetated and consisted of a mineral fraction to a minimum depth of 300 mm that would be suitable as a soil forming material.

6.4.6.1 Profile description

The profile consisted of a sand clay loam upper layer (Layer 1) to ~ 330 mm over a 170 mm sandy clay loam layer (Layer 2). This overlaid a layer of what appears to be ash to depth. Table 6.4.16 summarises the soil profile.

Table 6.4.16. Profile description for Site 1, Area 6

Site 1, Area 6			
Layer	1	2	Ash
Thickness (mm)	330	170	To depth
Texture	SCL	SCL	ash
Colour	10YR 6/1	7.5YR 5/6	
Average bulk density (g/cm^3)	1.38		
Ped shape	medium blocky/platy	massive	
Ped grade	moderately developed	apedal massive	
Ped strength	very firm	very strong/rigid	
% pores	10	0.1	
Boundary form from upper profile		wavy	smooth
Boundary distinctness from upper profile		clear	clear
Stone size (mm)	2 - 50	2 >150	
Stone abundance (%)	35	40	
Soil water state	moist	moist	
Max root depth (mm)	220		
Root abundance	few - fine		
Smell	No smell	No smell	No smell
Earthworm numbers	0		
Fungal hyphae	0		
Ped size (mm)	20 – 30	massive	
VESS/SubVESS	Sq4	Sq5	
Depth to Water Table	Not encountered		

6.4.6.2 Analytical results

Two samples were collected, one from the upper layer (Layer 1), and a second from Layer 2.

Based on LOI, the organic content in Layer 1 was low at 3.5% and the calculated organic content based on the DUMAS method was similar (3.4%, Table 6.4.17). Both methods found that Layer 2 had a low organic content of 3.1%.

Table 6.4.17. Organic content of mineral and organic layers

Site 1, Area 6				
	LOI (%)	Organic matter (%) (Dumas - calculated)	Suitability for agriculture	Environmental concern
Layer 1: upper (0 - 330 mm)	3.4	3.4		
Layer 2: (330 - 500 mm)	3.1	3.1		

The organic content in the upper soil horizon was low for a SCL and was therefore of moderate concern for both agriculture and as an indicator of restoration success.

Both methods used for available plant nutrient status found similar results for Layers 1 and 2 (Table 6.4.18). Available P was very low/index 0, K was low/index 0 or 1 and Mg was high/index 5.

Based on ADAS methods, the pH of Layer 1 was strongly alkaline with a pH of 7.9 but the CaCl method found it to be slightly acidic (pH 6.9). Both methods found that Layer 2 was moderately to strongly acidic, with the ADAS method showing a pH of 5.9 and the CaCl method a pH of 5.5.

Table 6.4.18. Plant-available nutrients and pH of the mineral fractions

Site 1, Area 6					
		SAC	ADAS	Suitability for agriculture	Environmental concern
Layer 1: upper (0 - 330 mm)	Available P (mg/l)	1.4(VL)	2.8(0)		
	Available K (mg/l)	55(L)	59.6(0)		NA
	Available Mg (mg/l)	398(H)	300(5)		NA
	pH	6.9	7.9		
Layer 2: (330 - 500 mm)	Available P (mg/l)	1.5(VL)	7(0)		
	Available K (mg/l)	69(L)	78(1)		NA
	Available Mg (mg/l)	303(H)	287(5)	NA	NA
	pH	5.5	5.9		

NA = Not Applicable

The low plant-available levels of P and K were of agricultural concern and were an indicator of poor restoration outcomes.

Heavy metal concentrations in the mineral fractions (Layers 1 and 2) were low, normal or of no specific concern.

6.5 Vegetation analysis

The full results of the vegetation survey and analysis are provided in Appendix 5a [Full vegetation analysis (Site 1)] and photographs of the study areas are provided in Appendix 6a [Photographs of vegetation (Site 1). A brief summary is given below. The nature and suitability of vegetation present is summarised in Table 6.5.1.

Table 6.5.1. Summary of the vegetation present in the six study areas at Site 1

Area	Vegetation cover	Vegetation health	No. of species	Summary of species distribution in area as a whole	Grazing value[1]	Ecological value[2]
1	complete ground cover; variable height, very dense	good	39	several weed species abundant or frequent, likely no sown species present.	poor	moderate
2	almost complete ground cover variable height, often tall and dense	good	54	as above	poor	moderate
3	almost complete ground cover variable height, often tall and dense	good	27	as above	poor	moderate
4a	complete ground cover; generally tall and very dense	good	15	as above	poor	poor
4b	low growing patchy vegetation, some bare soil	pale, small	35	varied, some legumes and no aggressive weed species were abundant or frequent	poor	moderate
5	complete ground cover; variable height, very dense	good	51	several weed species abundant or frequent, likely no sown species present.	poor	moderate
6	complete ground cover variable height, sometimes tall and dense	good	47	as above	poor	moderate

[1]Grazing value scores:

- very (v) poor: few plants present and those present growing poorly and/of low forage value;
- poor = plants of poor health/growing poorly; species of low forage value predominate;
- moderate = plants relatively healthy; some species with forage value present
- good = plants healthy/growing well and sward contains at least 50% species of forage value;
- very (v.) good = plants healthy/growing well and sward contains at least 70% species of forage value;

[2]Ecological value scores:

- very (v) poor = very few species and/or a lot of bare soil;
- poor = relatively few species, and/or one or more weed species frequent or abundant (see DAFOR, Appendix 2) and/or some bare patches;
- moderate = most soil covered, moderate number of species but one or more weed species frequent or abundant;
- good = complete/almost complete soil cover, a reasonable range of flowering species from different families incl. grasses and non-grasses;
- very (v.) good: complete soil cover with a good range of flowering species from different families incl. grasses and non-grasses.

<u>Area 1</u> - Vegetation cover was almost complete and generally very dense (Appendix 6a, Plate 1). There were 39 species present in the area and creeping soft grass and soft rush were abundant. Although the authors have heard unofficially (by “word of mouth”) that the area was sown, no written records exist of the species used, the rate at which the seed mixture was applied or the application method. It is unlikely that any of the species most commonly found in this area were sown, with the most frequent species being creeping soft grass, marsh thistle, soft rush, tufted hair grass, yorkshire fog and common sorrel. Although some of the species present had value for wildlife such as insects, spiders and the larger organisms which depend on them, the most abundant species were aggressive and of relatively low ecological value.

There were almost no bare patches of soil, with vegetation cover being almost complete other than on a very few small (a few square centimetres here and there) heavily compacted patches. Most plants, including the desirable grass species were of good health and had a size and colour consistent with their textbook descriptions. There was no evidence of nutrient deficiencies in the vegetation.

Area 2 - Vegetation cover was variable, often very tall and dense, but generally species-poor (Appendix 6a, Plate 2). There were 54 species present in the area but yorkshire fog was abundant and the number of plants of the other species was low. There were patches of species-rich flora, which seemed more common on the more compact parts of the site. Again, although the authors have heard unofficially (by “word of mouth”) that the area was sown, no written records exist of the species used, the rate at which the seed mixture was applied or the application method. It is unlikely that any of the species most commonly found in this area were sown, with the most frequent species being rosebay willowherb, broad-leaved willowherb, tufted hair grass, yorkshire fog, soft rush and greater birdsfoot trefoil. Some of these plants have useful ecological value, but there were relatively few of the more useful species (such as birdsfoot trefoil and rosebay willowherb). Most plants were of good health and had a size and colour consistent with their textbook descriptions. The nature and suitability of vegetation present is summarised in this and other areas at Site 1 in Table 6.5.1.

Area 3 - Vegetation cover was variable and often very tall and dense (Appendix 6a, Plate 3). There were relatively few (27) species present and soft rush was abundant. There were almost no bare patches and those which were present were only a few square cm in size. Again, although the authors have heard unofficially (by “word of mouth”) that the area was sown, no written records exist of the species used, the rate at which the seed mixture was applied or the application method. It is unlikely that any of the species most commonly found in this area were sown, with the most frequent species being creeping thistle, tufted hair grass, creeping soft grass, soft rush and creeping buttercup. Although some of the species present had value for wildlife such as insects, spiders and the larger organisms which depend on them, the most abundant species were aggressive and of relatively low ecological value.

Most plants were of good health and had a size and colour consistent with their textbook descriptions, although some appeared very dark green, as though they were growing in a soil which contained high concentrations of N. There was no evidence of nutrient deficiency. The nature and suitability of vegetation present is summarised in this and other areas at Site 1 in Table 6.5.1.

Area 4 - The area had reportedly been restored using sewage sludge (see Section 6.3) and although most of it (labelled Area 4a for the purposes of this vegetation analysis) probably has been, there was a very species-rich area which is unlikely to have had sludge applications (Area 4b). The soil samples for analysis were taken from Area 4a. Ten quadrats were examined in the area probably treated with sludge (Area 4a, which was more than 5 m south of the track) and two quadrats were examined (for comparison) in the area probably not treated with sludge (Area 4b, which was between the track and a line approximately 5 m south of the track). The nature and suitability of vegetation present is summarised in this and other areas at Site 1 in Table 6.5.1.

Area 4a (lying more than 5 m south of the East/West access track) was covered in dense, species-poor, dark green vegetation which was very hard to walk through (Appendix 6a, Plate 4). There were few patches of bare soil and there were no legumes in this area. There were 15 species present in this area, in which creeping thistle, soft rush and creeping buttercup were abundant. There were few examples of species which had much ecological value in this area and the most abundant species were aggressive and of relatively low ecological value.

This was in stark contrast to the vegetation in Area 4b (which lay within 5 m of the East/West track), which was considerably more species rich (35 species were recorded here, none of which were dominant or abundant). Although there were some areas of bare soil in this area, it contained several legume species, two of which were frequently occurring (red and white clover). These legume rich patches probably indicated a lack of RAN. Although the vegetation in this area was sparse, many of the species present had value for wildlife such as insects, spiders and the larger organisms which depend on them.

It is not known whether either parts of Area 4 were sown: no written records exist of the species used, the rate at which the seed mixture was applied or the application method. It is unlikely that any of the species most commonly found in this area were sown, with the most frequent species generally being classed as weed species with no agricultural value.

Most plants in the densely vegetated, species-poor Area 4a were of good health and had a size and colour consistent with their textbook descriptions, although some appeared very dark green, as though they were growing in a soil which contained high concentrations of N and P. There was no evidence of nutrient deficiency. In contrast, plants in the sparsely vegetated species-rich Area 4b were much smaller, with many appearing slightly stunted and pale.

Area 5 - There were almost no bare patches of soil, in this area, with vegetation cover being almost complete other than on a very few small (a few square centimetres here and there) heavily compacted patches (Appendix 6a, Plate 5). The dense growth was often difficult to walk though. 51 species were present in this area and tufted hair grass, yorkshire fog, creeping soft grass and soft rush were abundant. The number of plants of the other species was low. Again, although the authors have heard unofficially (by "word of mouth") that the area was sown, no written records have been found of the species used, the rate at which the seed mixture was applied or the application method. It is unlikely that any of the species most commonly found in this area were sown, with the most frequent species generally being classed as weed species with no agricultural value. Although some of the species present had value for wildlife such as insects, spiders and the larger organisms which depend on them, the most abundant species were aggressive and of relatively low ecological value.

Most plants, including the desirable species were of good health and had a size and colour consistent with their textbook descriptions. There was no evidence of nutrient deficiencies in the vegetation. The nature and suitability of vegetation present is summarised in this and other areas at Site 1 in Table 6.5.1.

Area 6 - This area had apparently not been restored using sewage sludge (see Section 6.3), although in some parts of the area walked (which were only 30 m from the original OS grid reference for the area) it appeared as though restoration had taken place, since the ground was covered in dense, deep green vegetation which was very hard to walk through (Appendix 6a, Plate 6). Much of the site was species-poor and some of the species present (such as nettle and dock) tend to thrive in soils rich in N and P. This was in stark contrast to other un-restored areas at Site 1 (outside Area 6), which contained a wide range of species, a high percentage of bare soil and the vegetation was generally low-growing and nutrient-deficient in appearance. Forty seven species were recorded in this area, with the abundant species being tufted hair grass, creeping soft grass and soft rush. The area was variable in terms of its ecological value, with some relatively species-rich patches, which tended to occur where the vegetation was lower in height and other areas which were species-poor and contained few species with much ecological value.

Although the authors have heard unofficially (by "word of mouth") that the area was sown, no written records exist of the species used, the rate at which the seed mixture was applied or the application method. It is unlikely that any of the species most commonly found in this area were sown, with the most frequently occurring species generally being classed as weed species with no agricultural value.

The health of the vegetation appeared generally good, with no evidence of nutrient deficiency. Most were of a normal green colour in accordance with their textbook descriptions, although some appeared very dark green indicating a soil rich in N and P. The nature and suitability of vegetation present is summarised in this and other areas at Site 1 in Table 6.5.1.

6.6 Land Capability of Restored Area

Ignoring climate, the primary considerations for the Land Classification for Agriculture (LCA) of Site 1 are drainage pattern and drainage limitations. All the treatment locations are currently unfit for livestock grazing due to the presence of holes, waste materials, lack of fencing/gates and access limitations. The rough land surface is currently unsuitable for the use of standard agricultural equipment and there are back lying areas with limited drainage potential. The site is currently classed as LCA 7: *Land of very limited agricultural value*.

With further remediation to remove hazards for livestock, deal with the rough land forms and to establish suitable drainage patterns, some sections of the site could be improved to LCA 5.3: *Land marginally suited to reclamation and use as improved grassland.*

Without additional remediation, the most appropriate Land Capability for Forestry Class is F5: *Land with limited flexibility for growth and management of tree crops*, with soil wetness and nutrients as the limitations (excluding climate). Standard forestry land preparation techniques could improve this to F4*: Land with good flexibility for the growth and management of tree crops* provided that the low phosphate levels are also addressed.

6.7 Conclusions on restoration success

The success of restoration at the six study areas at Site 1 is summarised in Table 6.7.1. The information in the table is based on that set out and discussed in more detail in earlier parts of the document.

The primary concern for the restoration outcomes at Site 1 was the continued presence of a discrete layer of sewage sludge within the soil profile, in all five of the restored areas investigated, 4 years after restoration was completed. In each instance, the remaining layer of sludge was at or below 300 mm. There was therefore little prospect that the benefits of sludge as a topsoil forming material and plant nutrient source will be realised. Given the luxurious nature of the weed growth in many of the areas examined, it looks as though nutrients have been present in the soil profile at an earlier time, but the soil analysis has shown that plant available nutrient concentrations are now low. It seems likely that the nutrients in the areas examined are mainly contained in the roots and shoots of the vegetation present. This phenomenon is common in many natural ecosystems: i.e. the soils are nutrient poor, and most of the nutrients present in the system are held in the plants and animals living there.

The main observations on vegetation and soils were as follows:

- Given that a key end use for the restored land at Site 1 was agricultural grazing, this restoration has been a failure. The land (in all five restored areas) was unsafe to walk on, and unsafe for livestock. The dangers were due to both the poor land forming in some parts (prior to restoration), which had left steep areas, hollows and open ditches, some of which were covered in vegetation and filled with water. The hazardous nature of the site was compounded by the amount of rock, brick, concrete and general rubbish which was abundant in parts. There were no gates or fences to contain livestock. The vegetation present on the site was often dense and vigorous, but it lacked diversity. The vegetation was dominated by weed species of low ecological value which had extremely limited forage value for livestock.

- Although vegetation was sparse on un-restored areas at Site 1, the vegetation on un-restored areas was often more species-rich than that on the restored areas. The un-restored areas often included some rarities, such as a range of orchid and sedge species.

- At each of the restored study areas, a discrete layer and/or deposit of sewage sludge occurred at or below 300 mm within the soil profile. This layer (or deposits covering part of the profile) ranged in thickness from 110 to over 250 mm. Based on a sewage sludge wet bulk density of 1.2 kg/l, the target sewage sludge application rate (400 - 500 t/ha across all the restoration areas) can be fully accounted for by what was found to be remaining as unincorporated layers in the soil profiles. It must be concluded therefore that all the sewage sludge applied at the Site 1 as part of the restoration process now comprises these remaining layers of sewage sludge. This is supported by the low to very low concentrations of plant-available P that were found in the upper layers at each study area. Sewage sludge is recognised as being a good source of P, which should have been found in the upper 30 cm of the soil profile, had successful incorporation occurred.

- Since it appeared that most of the applied sewage sludge has been buried at inappropriate depths, it may be the case that the organic matter and generally low concentrations of plant-available nutrients present in the upper soil profiles have come from other sources, such as the use of pre-existing topsoil.

- Where plant roots had extended down to reach the top of the sewage sludge layers, it was apparent that they were unable to grow into the sludge. The sludge was therefore acting as a barrier to plant growth.

- There was limited evidence of mixing between the remaining sewage sludge and the mineral fraction of the profiles. There was no realistic expectation that the sludge is currently or will in the future act as part of the topsoil formation process or as a plant nutrient source.

- The eventual anaerobic decomposition of these sewage sludge layers and deposits is likely to result in localised slumping of the soil surface. This may already be happening in some parts of the areas walked, since the soil surface is extremely uneven in places and it is hard to imagine that it had been left like that shortly after restoration. It is expected that any nutrients released during the development of slumping will be lost to leaching or retained in the subsoils at depths that are below the rooting zone of most target plant species.

- The control area (Area 6) had had no sludge applied (across most of it), but in fact the soil nutrient status and pH were not very different from those in the upper soil layers in the restored areas. This was due to the fact that soil nutrient status and pH in the restored areas were too low, just as they were in Area 6. Soil structural development had occurred to an extent in Area 6, but this was limited to the upper soil layer only. It is speculated that the more advanced and deeper soil structural development observed in the areas that were treated (1 – 5), as compared to the control, is due to the double digging process itself which will have alleviated compaction and improved local drainage capacity in the medium term (5 years) and the use of pre-existing topsoil in the original restoration.

- The overall conclusion from this investigation is that the restoration at Site 1 was not successful. The site is completely inappropriate for any form of agricultural use as it stands, it is unsafe for public access, is of limited value for wildlife and poses some degree of risk to the surrounding environment due to the potential for P to leach into local watercourses.

Table 6.7.1. Summary of the environmental risk, agricultural potential, suitability of current vegetation cover and overall success of restoration at the six study areas at Site 1.

Area	Environmental risk (ER)[1]	Agricultural potential (AP)[2]	Current vegetation cover suitable for[3]		Success of restoration (SRest)[4]	Comments
			Agriculture	Ecology		
1	high	very poor	poor	moderate	very poor	• ER high due to presence of (RAN/P-rich) buried sludge layer (> 600 mm depth). • AP v.poor due to compaction in soil and VL plant-available P in topsoil. • SRest very poor due to the above and to the presence of higher plant available K concentrations in lower layers than in topsoil.
2	high	very poor	poor	moderate	very poor	• ER high due to presence of (RAN/P-rich) buried sludge layer (300-500 mm depth). • AP v.poor due to compaction, acidity (pH 4.4-5.5) and L/VL plant-available P in topsoil. • SRest very poor due to the above and to the presence of higher plant available K concentrations in lower layers than in topsoil.
3	high	very poor	poor	moderate	very poor	• ER high due to presence of (RAN/P-rich) buried sludge layer (390-640 mm depth). • AP v.poor due to compaction, acidity (pH 4.8-5.3) and VL plant-available P in topsoil. • SRest very poor due to the above and to the presence of higher plant available K concentrations in lower layers than in topsoil.
4	high	very poor	4a poor 4b poor	4a poor 4b moderate	very poor	• ER high due to presence of (RAN/P-rich) buried sludge layer (350-570 mm depth). • AP v.poor due to compaction, acidity (pH 4.6-5.5) and possibly L plant-available P in topsoil. • SRest very poor due to the above.
5	high	very poor	poor	moderate	very poor	• ER high due to presence of (RAN/P-rich) buried sludge layer (590-700 mm depth). • AP v.poor due to compaction and VL plant-available P in topsoil. • SRest very poor due to the above.
6	low	very poor	poor	moderate	not restored	• Area was not restored • ER low because no nutrients or sludge have been applied. • AP v.poor due to compaction, relatively low soil OM content and VL plant-available P/K in topsoil.

[1]Environmental risk: low, moderate or high;
[2]Agricultural potential (given the potential LCA class for this area): very poor, poor, moderate, good or very good, depending on the soil physical and chemical characteristics;
[3]Suitability of current vegetation cover: for: agriculture (based on amount and health of vegetation present and forage value of species present) and
ecology (based on species diversity and presence of useful species);
[4]Success of restoration: very poor, poor, moderate, good or very good (an assessment which depends on the environmental risk, the agricultural potential and current vegetation of the area).
NB: Further details for each area are provided under "Comments above" and in sections 6.4 and 7.4).

7 Site 2

7.1 Broad site description and restoration practice

Mining operations at Site 2 ceased in 2013 and land forming and restoration began shortly afterwards. The site is being restored to agriculture (rough and improved grazing). Parts of the land have already been handed back to the farming tenant, and cattle are now grazing on it.

Records of the intended restoration practices have been made available (in the form of Paragraph 8 (2) and 9 WMLEs. Verbal information on restoration practices used was also gained from staff managing and working at the site. The general intention was to use sewage sludge at rates of between 198 and 400 t/ha to improve soils on the site. According to the land restoration contractor, this was incorporated into soil in two main ways: either through surface application and cultivation to a depth of 30 cm, or by placing sludge into the base of 40 cm deep trenches formed during double-digging. Each sludge layer was covered in soil from the base of the next trench to be dug. Small volumes of peat from the site were also used and waste gypsum from an industrial process was also used across the site at 50 t/ha. It was surface applied under a Paragraph 9 WMLE after sludge application.

7.2 Initial site survey

The site was visited on 3rd July 2017 with staff from the restoration contractor responsible for the site and a thorough inspection was made of the site (with brief soils investigations) with a view to choosing six areas for detailed study. Six study areas were then chosen to represent un-restored land and land restored using each of the two sludge incorporation methods used on the site. The study areas, and the restoration practices which were registered with SEPA are briefly described in Section 7.3. Details of the initial site survey are recorded in Appendix 1.

7.3 Description of six individual study areas

Areas 1 and 2 (both 5 ha) lay in the far west of the site, nearest to the main site entrance. Both had been restored by applying sludge (and calcium sulphate) to the soil surface and discing it in to the top 30 cm. The land forming had been well done, the soil surface was smooth, there were no surface stones larger than a few cm in diameter. The soil surface was covered in vegetation (mainly grass species, see Section 7.5) which was periodically being grazed by cattle. The land had been fenced and there were well-surfaced tracks leading to good, safe livestock gates in all fields. Restoration in Areas 1 and 2 took place in 2014 and the methods used are summarised in Table 7.3.1.

Areas 3, 4 and 5 (each were approximately 5 ha in size). All lay in the west of the site. Both had been restored by a double-digging (shallow trenching) method whereby a trench was dug to a depth of 40 cm, the trench was filled with sludge then the trench was topped with soil material from the base of the next trench. The land forming and restoration had been well done, the soil surface was smooth and there were no surface stones larger than a few cm in diameter. The soil surface was covered in vegetation (grass and weed species, see Section 7.5) which was periodically being grazed by cattle. The land had been fenced and there were well-surfaced tracks leading to good, safe livestock gates in all fields. Restoration in Areas 3, 4 and 5 took place in the 2013. The methods used are summarised in Table 7.3.2.

Table 7.3.1 Restoration practice in Areas 1 and 2	
Total amount requested under this exemption	Have no copy of the renewal for this WMLE and no waste return relevant to these areas. Only have the first (Para. 8) application and the waste data return for that.
Application rate	400 t/ha requested, but only 198 t/ha applied (according to Restoration Company) along with 50 t/ha of calcium sulphate
Application method	Sludge was applied to the soil surface and disced in to a depth of around 30 cm. Calcium sulphate was applied to the soil surface and cultivated in, after the sludge cultivations.
Restored area	Not known, since the original WMLEs were not available.
Habitats to be established	Grassland for grazing by cattle and sheep.

Table 7.3.2. Restoration practice in Areas 3, 4 and 5	
Total amount requested under this exemption	25,000 tonnes
Application rate	400 t/ha requested, but only 198 t/ha applied (according to Restoration Company) along with 50 t/ha of calcium sulphate.
Application method	Sludge was incorporated into the base of 40 cm deep trenches formed during double-digging. Each sludge layer was covered in soil from the base of the next trench to be dug. Calcium sulphate was applied to the soil surface and cultivated in, after the double digging process.
Restored area	Waste data return indicated that 26,245 tonnes had been applied. Had this been applied at intended application rate of 400 t/ha then 66 ha would have been restored under this WMLE. Had this been applied at 198 t/ha then 133 ha would have been restored under this WMLE.
Habitats to be established	Grassland for grazing by cattle and sheep.

Area 6 (Approximately 5 ha) lay in the East of the site. This area was land-formed (i.e. hollows filled in and heaps levelled) at the same time as the rest of the land on the site. It has not had any organic materials applied to date. The surface of the soil forming materials was heavily compacted and was thought to represent the condition of most of the land prior to full restoration (which involved relief of compaction, incorporation of organic materials and sowing).

7.4 Soil assessment and analysis

The results of the soil profile assessments and a summary of the soil analysis data are provided in the following sections. Photographs of the soil pits are shown in Appendix 3 (Photographs of soil pits) and the PDFs of full laboratory analysis data are presented in Appendix 4 (Soil and sludge analysis).

The soils in Areas 1 and 2 were similar to each other. They were generally drier than those in Areas 3, 4 and 5.

7.4.1 Site 2 Area 1

The soil was a medium textured sandy clay loam soil to between 250 and 280 mm (Layer 1) overlying a 320 mm layer of compacted sandy clay loam subsoil (Layer 2) and this overlaid rock. The profile was consistent and had clear and smooth boundaries.

The upper layer (Layer 1) was a developing topsoil with good rooting potential to at least 220 mm and with a reasonable coarse, platy structure. Gypsum was obvious and diffusely mixed to a depth of 200 mm. Mottling was present (few) in the upper 140 mm but was restricted to the zones around the roots which were common to this depth. Layers 1 and 2 are deemed to have derived from the same parent material but there was a notable colour change between the two layer with Layer 1 having a darker value which was attributed to its higher organic content. This colour change, along with differing structures marked the major distinction between the upper layer (Layer 1) and Layer 2, which was consistent with topsoil development.

Layer 2 was heavily compacted and had a wetness class of IV, but there were no obvious indications of serious drainage restrictions in the upper 400 mm. This might have been expected, given the sloping nature of the land.

7.4.1.1 Profile description

Table 7.4.1 summarises the soil profile.

Table 7.4.1. Profile description for Site 2, Area 1

Site 2, Area 1			
Layer	1	2	Stone
Thickness (mm)	250 - 280	320	
Texture	sandy clay loam	sandy clay loam	
Colour	10YR 3/2	10YR 3/5	
Average bulk density	1.47	not obtainable	
Ped shape	medium to coarse platy	coarse platy	
Ped grade	moderately developed	weakly developed	
Ped strength	weak to firm	firm	
% pores	10	2	
Boundary form from upper profile		smooth	smooth
Boundary distinctness from upper profile		clear	clear
Stone size (mm)	2 – 200	2 > 300	2- >1000
Stone abundance (%)	20	70	95
Soil water state	moist	moist	
Max root depth (mm)	140	NA	
Root abundance	common		
Smell	No smell	No smell	No smell
Earthworm numbers	2		
Fungal hyphae	common	none	
Ped Size	5 - 50	30 -70	
VESS/SubVESS	Sq3	Ssq4	
Depth to Water Table	Not encountered		

7.4.1.2 Analytical results

Two samples were collected, one from the upper layer (Layer 1) and the second from Layer 2.

The organic content in Layer 1 was low at 5.2% and lower still (3.4%) for the underlying layer (Layer 2) based on LOI (Table 7.4.2). The calculated organic content was higher (6.3%) for the upper layer but the results were the same for Layer 2 with both test methods.

Table 7.4.2. Organic content of mineral and organic layers

Site 2, Area 1				
	LOI (%)	Organic matter (%) (Dumas - calculated)	Suitability for agriculture	Environmental concern
Layer 1 Upper layer (0 - 280 mm)	5.2	6.3		
Layer 2 (280 - 320 mm)	3.4	3.4		

Both measures indicated good restoration outcomes for organic matter content, which was low but adequate. This was supported by the colour changes and structure development notes in the profile description.

The two methods used for available nutrient content showed similar results for Layer 1, with P being moderate/index 2, K moderate/index 1 and Mg high/index 3 (Table 7.4.3). Both methods showed that P was low/index 1 and Mg high/index 5 in Layer 2, but the SAC method showed that available K was moderate where the ADAS method showed that it was only index 1.

Table 7.4.3. Plant-available nutrients and pH of the mineral fractions

Site 2, Area 1					
		SAC	ADAS	Suitability for agriculture	Environmental concern
Layer 1 upper (0 - 280 mm)	Available P (mg/l)	5.3(M-)	16.8(2)		
	Available K (mg/l)	90(M-)	96.5(1)		NA
	Available Mg (mg/l)	231(H)	168(3)		NA
	pH	7	7.2		
Layer 2 (280 - 320 mm)	Available P (mg/l)	2.8(L)	9.6(1)		
	Available K (mg/l)	127(M-)	113(1)		NA
	Available Mg (mg/l)	449(H)	278(5)	NA	NA
	pH	7.2	7.8		

NA = Not Applicable

Using the ADAS method, the pH of Layer 1.1 was alkaline (pH 7.2) and with a CaCl extraction, the pH was similar (pH 7.0). The ADAS methods gave a strongly alkaline pH of 7.8 in Layer 2 and the CaCl extraction gave a lower pH of 7.2.

In Area 1, the restoration was successful in terms of agriculture, it posed no environmental concerns and represented a successful restoration outcome. The presence of plant-available P in the upper layer combined with the presence of organic matter was indicative of an effective mixing of sewage sludge with the mineral fraction.

Heavy metal concentrations in the mineral fractions (Layers 1 and 2) were low, normal or of no specific concern.

7.4.2 Site 2, Area 2

The medium textured sandy clay loam to sandy loam soil to 150 mm (Layer 1) overlaid a sandy loam to sandy clay loam subsoil (Layer 2) with a very high (>80%) stone content to depth. The stone content in the upper soil profile was also very high (~45%) and there were large (>500 mm) stones present. There were indicators of topsoil formation but this was restricted to the upper 150 mm and the remaining profile was treated as one.

The presence of gypsum was obvious: it was diffusely mixed into the upper 150 mm.

Layer 1 was distinctly different from Layer 2 in terms of both colour and structural development, but the high stone content was the dominant feature in both layers. Potential rooting depth was limited by the stone fraction but roots were common to ~130 mm. Drainage was reasonable to 380 mm. Below this depth, the degree of compaction increased and an obvious potential drainage restriction occurs.

7.4.2.1 Profile description

Table 7.4.4 summarises the soil profile.

Table 7.4.4. Profile description for Site 2, Area 2

Site 2, Area 2		
Layer	1	2
Thickness (mm)	150	> 700
Texture	SL - SCL	SCL
Colour	7YR 5/2	7YR 4/7
Average bulk density	1.61	not obtainable
Ped shape	fine blocky	massive
Ped grade	weakly developed	massive
Ped strength	moderately firm	
% pores	10	2
Boundary form from upper profile		clear
Boundary distinctness from upper profile		smooth
Stone size (mm)	2 – 20 mm (some very large stones >500 mm present)	2 - > 400
Stone abundance (%)	45	80
Soil water state	moist	wet
Max root depth (mm)	170	
Root abundance	common	
Earthworm numbers	1	
Smell	No Smell	No Smell
Fungal hyphae	few	
Ped size (mm)	10	
VESS/SubVESS	SQ3/4	SSq4
Depth to Water Table	Not encountered	

7.4.2.2 Analytical results

Two samples were collected, one from the upper layer (Layer 1) and the second from the upper half of Layer 2.

The organic content in Layer 1 was moderate to high at 9.3% and lower (6%) in the underlying layer (Layer 2) based on LOI (Table 7.4.5). The calculated organic content was higher (10% for Layer 1 and 6.1% for Layer 2).

The levels of organic matter in the upper profile indicated that the soil was suitable for agriculture and that there had been a good restoration outcome.

Table 7.4.5. Organic content of mineral and organic layers

Site 2, Area 2				
	LOI (%)	Organic matter (%) (Dumas - calculated)	Suitability for agriculture	Environmental concern
Layer 1 upper (0 - 150)	9.3	6.3		
Layer 2 (150 - > 700 mm)	10	6.1		

The results of the two methods used for available P content differed for Layer 1: the SAC method showed P levels as low, whereas the ADAS method gave an index of 2 (which is normally thought to be equivalent to SAC moderate, Table 7.4.6). Results using the two methods gave similar results for K (low or index 1) and Mg (moderate or index 2). In Layer 2, the results obtained from both methods were similar.

Table 7.4.6. Plant-available nutrients and pH of the mineral fractions

Site 2, Area 2					
		SAC	ADAS	Suitability for Agriculture	Environmental Concern
Layer 1 upper (0 - 150)	Available P (mg/l)	3.7(L)	23.6(2)		
	Available K (mg/l)	70(L)	64.8(1)		NA
	Available Mg (mg/l)	124(M)	98.5(2)		NA
	pH	6	6.3		
Layer 2 (150 - > 700 mm)	Available P (mg/l)	1.9(L)	6(1)		
	Available K (mg/l)	150(M+)	134(2-)		NA
	Available Mg (mg/l)	327(H)	228(4)	NA	NA
	pH	7.4	7.6		

NA = Not Applicable

Based on ADAS methods the pH of Layer 1 was moderately acidic, with a pH of 6.3 but the CaCl method resulted in a slightly lower pH of 6.0. Layer 2 was alkaline with a pH of 7.6 and 7.4 based on the ADAS and CaCl methods respectively.

The low levels of plant-available P and K in Layer 1 were a concern for agriculture and the low P was also recorded as being of poor restoration success. Sewage sludge is a typically an excellent source of P, yet there was little P in the soil mineral layers.

7.4.3 Site 2, Area 3

The soil was a fine textured sandy loam to medium textured sandy clay loam soil (Layer 1) to 120 mm over a 280 mm layer of similar textured soil (Layer 2). This overlaid a layer of sewage sludge (Layer 3) that had a minimum thickness of 350 mm. In sections of the pit, the final depth of the sewage sludge could not be determined due the occurrence of large stones (>400 mm) that could not be excavated. The sludge appeared to be mixed with the stones.

The distinction between layers 1 and 2 was subtle and based on differences in structure and colour. In addition, Layer 2 was diffusely mixed with peat or a peat-like material. Roots were plentiful and deep, reflecting the good overall rooting potential of the soil. There were no drainage restrictions in the upper profile but the sludge/stone mixture at ~700 mm was saturated highlighting the poor drainage potential of the land. The upper profile appeared heavily mottled, but this was thought to be due to the mixture of different soil forming materials used. Some mottling was present around roots but was not extensive.

The sewage sludge smell was very strong throughout the profile

7.4.3.1 Profile description

Table 7.4.7 summarises the soil profile.

Table 7.4.7. Profile description for Site 2, Area 3

Site 2, Area 3			
Layer	1	2	Sludge
Thickness (mm)	120	280	350
Texture	SL - SCL	SL -SCL	
Colour	7.5YR 5/3	7.5 YR 6/2	
Average bulk density	1.31	1.44	
Ped shape	fine to medium blocky structure	medium to course blocky	
Ped grade	moderately developed	weakly developed	
Ped strength	moderately firm	very firm	
% pores	10	2	
Boundary form from upper profile		wavy	irregular
Boundary distinctness from upper profile		clear	abrupt
Stone size (mm)	2 – 40	2 - 40	
Stone abundance (%)	30	30	
Soil water state	moist	wet	
Max root depth (mm)	340		
Root abundance	few to common		
Earthworm numbers	3		
Smell	no smell	no smell	strong sludge smell
Fungal hyphae	few		
Ped Size (mm)	5 - 30	20 - 45	
VESS/SubVESS	Sq2	Ssq2	
Depth to Water Table	Not encountered		

7.4.3.2 Analytical results

Two samples were collected: one from the Layer 1 and one from the sewage sludge layer (Layer 3). A third sample should have been collected from Layer 2, but the occurrence of the sewage sludge prevented this due to health and safety concerns.

The organic content in the upper horizon was low at 3.5 % (based on LOI, Table 7.4.8). The Dumas method found that it was even lower at 2.4%. The sludge layer had a high organic content of 24% based on LOI and 37% based on the calculated Dumas method.

Table 7.4.8. Organic content of mineral and organic layers

Site 2, Area 3				
	LOI (%)	Organic matter (%) (Dumas - calculated)	Suitability for agriculture	Environmental concern
Layer 1 upper (0 - 120 mm)	3.4	2.4		
Layer 3 SS layer (280 - > 550 mm)	24.3	36.5		

The low organic matter levels in Layer 1 were highlighted as a concern for agriculture as was the high organic content of the sludge layer. The presence of an organic layer (Layer 3) was acting as a drainage restriction and will, in the long term result in localised slumping of the surface. For the same reasons, the organic matter present in Layer 3 was highlighted as a poor restoration outcome. The sludge layer has also been highlighted as a potential environmental concern, as its depth in the soil profile means it will not contribute to topsoil development and will not serve as a source of plant nutrient. In the long term, the nutrients released by the anaerobic decomposition of the sludge layer will pose a risk to ground and surface water.

Both nutrient extraction methods showed that Layer 1 was very low or low/index 0 or 1 in both P and K and high/index 4 in Mg (Table 7.4.9). Both methods found that the pH was very low in Layer 1, with the ADAS method showing a pH of 4.8 and the CaCl extraction a pH of 4.3.

Table 7.4.9. Plant-available nutrients and pH of the mineral fractions

Site 2, Area 3					
		SAC	ADAS	Suitability for agriculture	Environmental concern
Layer 1 upper (0 - 120 mm)	Available P (mg/l)	1.5(VL)	4.7(0)		
	Available K (mg/l)	48(L)	48.4(0)		NA
	Available Mg (mg/l)	224(H)	190(4)		NA
	pH	4.3	4.7		

NA = Not Applicable

The low levels of plant-available P and K in Layer 1 were highlighted as a concern for agriculture and the low P was highlighted as an indicator of a poor restoration outcome. Sewage sludge is an excellent source of P, yet there was very little P in the upper soil profile.

Heavy metal concentrations in the mineral layer (Layer 1) were low, normal or of no specific concern. Analysis showed that the sludge was typical for a stabilised cake, aside from its total P and N content which were lower than commonly used reference values (Appendix 4). The heavy metal concentrations were typical for sewage sludge.

7.4.4 Site 2, Area 4

The soil was a fine textured sandy loam to medium textured sandy clay loam soil (Layer 1) to ~ 280 mm over a 250 mm layer of similar textured soil (Layer 2). This overlaid a layer of sewage sludge (Layer 3) with a variable thickness ranging from 200 – 400 mm.

The distinction between the two upper mineral layers was subtle and was marked by changes in both colour and soil structure. In some sections, the boundary was defined by the presence of peat "lenses" that have not been fully incorporated and extended into layer 2. There were no indications that the peat was "natural" and it was thought that the intention was to mix it in as part of the restoration as it is only partially humified (it had a Von Post score of H4 – H5, which is not typical of discrete peat layers found in mineral profiles).

At ~ 500 mm there was a compacted layer of mineral soil directly over the sewage sludge. This compacted layer was restricting drainage and the sludge was below its plastic limit. There was clear evidence of topsoil development in the upper profile and the sward was well established, with good rooting potential to 300 mm.

7.4.4.1 Profile description

Table 7.4.10 summarises the soil profile.

Table 7.4.10. Profile description for Site 2, Area 4

Site 2, Area 4				
Layer	1	2	Sludge (3)	4
Thickness (mm)	280	250	200 - 400	To depth
Texture	SL -SCL	SL - SCL	SS	SCL
Colour	7.5 YR 4/2	7.5 4/2		7.5 4/2
Average bulk density	1.55	1.66		
Ped shape	medium blocky	course blocky		apedal
Ped grade	moderately developed	weakly developed		
Ped strength	moderately firm	very firm		
% pores	5	2		
Boundary form from upper profile		wavy	irregular	
Boundary distinctness from upper profile		gradual	abrupt	
Stone size (mm)	2 - 30	2 - 30		
Stone abundance (%)	25	30		
Soil water state	moist	wet		
Max root depth (mm)	160			
Root abundance	common			
Smell	no smell	no smell	Moderate sludge smell	Moderate sludge smell
Earthworm numbers	4			
Fungal hyphae	common			
Ped size (mm)	10-20	> 20		
VESS/SubVESS	Sq3	Ssq4		
Depth to Water Table	Not encountered			

7.4.4.2 Analytical results

Three samples were collected, one from the upper layer (Layer 1), one from Layer 2 and the third from the sewage sludge layer (Layer 3).

The organic matter levels were moderate in Layer 1 at between 9 and 11% depending on the analytical method used (Table 7.4.11). Organic matter content was higher (10 to 15%) for the Layer 2. The sludge layer (Layer 3) had a high organic matter content of at least 65%.

Table 7.4.11. Organic content of mineral and organic layers

Site 2, Area 4				
	LOI (%)	Organic matter (%) (Dumas - calculated)	Suitability for agriculture	Environmental concern
Layer 1 (0 - 280 mm)	8.8	11.8		
Layer 2: (280 -530 mm)	9.6	15		
Layer 3: SS layer (530 - > 700 mm)	72.8	65.2		

The organic matter levels in Layer 1 were suitable for agriculture and represented a good restoration outcome. The increasing organic matter content with depth culminated in the very high organic matter levels found in the sewage sludge. These high levels were a concern for agriculture as they will reduce drainage potential and in the long term will result in localised slumping and subsidence. The buried sludge layer posed an environment risk to groundwater and indicated a poor restoration outcome, since the sludge was too deep to give benefit to the topsoil or act as a plant nutrient source.

7.4.4.3 Analytical results

The nutrient levels in Layer 1 were very low/index 0 for P and low/index 1 for K (depending on the method used, Table 7.4.12). Plant P and K availability was higher lower down in the profile (in Layer 2). Extractable Mg concentrations were high/index 4 or 5 in both layers when tested with either method.

Table 7.4.12. Plant-available nutrients and pH of the mineral fractions

Site 2, Area 4					
		SAC	ADAS	Suitability for Agriculture	Environmental Concern
Layer 1: upper (0 - 280 mm)	Available P (mg/l)	1.6(VL)	5.4(0)		
	Available K (mg/l)	74(L)	70.7(1)		NA
	Available Mg (mg/l)	390(H)	300(5)		NA
	pH	4.7	5.4		
Layer 2: above SS (280 - 530mm)	Available P (mg/l)	4.9(M-)	17(2)		
	Available K (mg/l)	151(M+)	137(2-)		NA
	Available Mg (mg/l)	314(H)	228(4)	NA	NA
	pH	6.4	6.6		

NA = Not Applicable

The pH of Layer 1 was acidic with a pH of between 4.7 and 5.4 (depending on the method used). The pH lower down in the profile was higher (between 6.4 and 6.6 depending on the method used).

The low P and K status of Layer 1 was highlighted as being of concern for agriculture. The low P status is also highlighted as a poor restoration outcome. Sewage sludge is an excellent source of P, yet there was little evidence that it was contributing to soil P status in layer 1. The pH in Layer 1 is also classed as a concern for both agriculture and restoration outcome, since it is low (and considerably lower than the pH of Layer 2).

The increase in P status in Layer 2 (compared with Layer 1) is a concern for the environment, because this P will be largely un-accessible to plants. It therefore poses a risk to groundwater. The high P and K levels in Layer 2 are also highlighted as representing a poor restoration outcome, since it appears that these nutrients have been buried below 300 mm.

Heavy metal concentrations in the mineral layers (Layer 1 and 2) were low, normal or of no specific concern. Analysis showed that the sludge contained typical concentrations of total N, P, K and heavy metals (Appendix 4).

7.4.5 Site 2, Area 5

The soil had a medium textured SCL upper layer (Layer 1) to between 160 and 220 mm overlaying a broken deposit of sewage sludge that varied in thickness between 20 – 120 mm. This overlaid a medium textured clay subsoil (Layer 2) that is best described as boulder clay.

A sewage sludge deposit (Layer 2) sometimes occurred within this layer. It has a thickness of at least 20 mm across and occurred ~ 70% of a 1.5 m wide face. It appeared to be a ball of sludge (see Photographs in Appendix 3) that had been partially smeared onto the subsoil layer. Where sewage sludge was absent, the upper layer (Layer 1) sat directly over the lower mineral layer (Layer 3).

There was a strong distinction between Layers 1 and 3 which was marked by changes in colour and soil structure. The differences were consistent with the transition from a topsoil to subsoil horizon, but the lower layer (Layer 3) was massive (coherent) with limited drainage potential.

It was noted that where the sewage sludge layer was 50 mm or greater in thickness, there was no penetration of roots into or past the sludge layer.

7.4.5.1 Profile description

Table 7.4.13 summarises the soil profile.

7.4.5.2 Analytical results

Three samples were collected: one from the upper layer (Layer 1), a second from the lower mineral layer (Layer 3) and a third from the partial layer of sewage sludge (Layer 2).

The organic matter level in Layer 1 was moderate and adequate at 5.6 to 5.8% (depending on the method used, Table 7.4.14). Organic matter content was higher (from 26.7 to 37.6%) in the sludge layer (Layer 2) and was very low (1.3 to 1.8%) in the underlying mineral layer (Layer 3).

The organic matter in the upper layer was moderate and was deemed suitable for agriculture and was thought to represent a successful restoration outcome. The continued presence of a sewage sludge layer high in organic matter below 220 mm was deemed as unsuitable for agriculture, as it was noted that roots were unable to grow into or through the sludge layer when it was 50 mm or greater in thickness. The sludge layer was therefore restricting rooting. The presence of sludge at this depth in the soil profile also poses a potential environmental concern, since the sludge has little potential to contribute to further topsoil development and is too deep to be a useful source of plant nutrients.

Plant-available P concentrations were moderate or index 4 in Layer 1, but K levels were low or index 0 (Table 7.4.15). In the lower mineral layer (Layer 3), soil P levels were low or index 0 and K levels were moderate or index 1. Mg levels were high or index 5 in both layers.

Table 7.4.13. Profile description for Site 2, Area 5

Site 2, Area 5			
Layer	1	Sludge (2)	3
Thickness (mm)	160 – 220	20 -120	
Texture	SCL		SCL - CL
Colour	2.5 YR 5/0	2.5 YR 5/2	
Average bulk density	1.48		1.62
Ped shape	medium blocky		apedal
Ped grade	moderately developed		
Ped strength	moderately weak		
% pores	2		0.5
Boundary form from upper profile		broken	broken
Boundary distinctness from upper profile		clear	abrupt
Stone size (mm)	25		30 - 50
Stone abundance (%)	15		30
Soil water state	moist		moist
Max root depth (mm)	240		
Root abundance	common		
Smell	no smell	Sludge Smell	Sludge Smell
Earthworm numbers	4		
Fungal hyphae	few		
Ped size	5 - 10		
VESS/SubVESS	Sq3		SSq4
Depth to Water Table	Not encountered		

Table 7.4.14. Organic content of mineral and organic layers

Site 2, Area 5				
	LOI (%)	Organic matter (%) (Dumas - calculated)	Suitability for agriculture	Environmental concern
Layer 1: upper (0 - 220 mm)	5.6	5.8		
Layer 2: SS layer (220 - 350 mm)	32.8	26.7		
Layer 3: Below SS layer (350 - > 500)	1.8	1.3		

The pH of the upper layer (Layer 1) was strongly acidic (4.9 to 5.2 depending on the method used). Soil pH was much higher (6.7 to 7.0) in the lower mineral layer (Layer 3).

The moderate to high levels of plant-available P in Layer 1 was as expected, given the fact that sludges were used during restoration. These levels are regarded as being suitable for agriculture and an indication of a good restoration outcome. The low or very low K status in Layer 1 was of moderate concern, but is expected as sewage sludge is not typically high in potassium. The low pH of the layer 5.1 was a concern for agriculture and has been highlighted as a restoration concern, particularly since the pH of the lower mineral layer is higher.

Heavy metal concentrations in the mineral layers (Layers 1 and 2) were low, normal or of no specific concern.

Analysis showed that the sludge contained typical concentrations of total N, P, K and heavy metals (Appendix 4).

Table 7.4.15. Plant-available nutrients and pH of the mineral fractions

Site 2, Area 5					
		SAC	ADAS	Suitability for agriculture	Environmental concern
Layer 1: upper (0 - 220 mm)	Available P (mg/l)	9.8(M+)	56(4)		
	Available K (mg/l)	42(L)	35.5(0)		NA
	Available Mg (mg/l)	231(H)	168(3)		NA
	pH	4.9	5.2		
Layer 3: below SS layer (350 - > 500)	Available P (mg/l)	2(L)	6.2(0)		
	Available K (mg/l)	96(M-)	82.2(1)		NA
	Available Mg (mg/l)	370(H)	264(5)	NA	NA
	pH	6.7	7		

NA = Not applicable

7.4.6 Site 2, Area 6

This area was chosen in an attempt to include a control in order to aid understanding of the restoration and its outcomes. This was only partially achieved as the only area available was used as a roadway and staging area. The position chosen was partially vegetated and consisted of a mineral fraction to at least 150 mm that would be suitable as a topsoil formation material.

The soil was a medium textured sandy loam upper layer to between 120 and 170 mm, which overlaid a 220 to 250 mm layer of sandy loam. Below this consisted of large (>1000 mm) stones.

The primary distinction between Layers 1 and 2 was the increase in stone content and the degree of compaction, which was greater in the lower layer (Layer 2).

7.4.6.1 Profile description

Table 7.4.16 summarises the soil profile.

7.4.6.2 Analytical results

A single sample was taken from the upper layer (Layer 6). The organic matter content was found to be low to very low (1.9 to 3.2 depending on the method used, Table 7.4.17). This level was deemed unsuitable for agriculture.

The levels of plant-available P were very low or index 0, levels of K were moderate or index 1 and levels of Mg were high/index 5 (Table 7.4.18). The pH was slightly to moderately alkaline, depending on the method used.

Heavy metal concentrations in the mineral layer tested (Layer 1) were low, normal or of no specific concern.

Table 7.4.16. Profile description for Site 2, Area 6

Site 2, Area 6			
Layer	1	2	Stone
Thickness (mm)	120 - 170	220 - 250	
Texture	SL	SL	
Average bulk density	1.69	NA	
Ped shape	blocky	apedal	
Ped grade	weakly developed	granular	
Ped strength	moderately firm	loose	
% pores	15	2	
Boundary form from upper profile		wavy	wavy
Boundary distinctness from upper profile		clear	clear
Stone size (mm)	2 > 50	2 - 300	
Stone abundance (%)	40	80	
Soil Water state	moist	moist	
Max root depth (mm)	125		
Root abundance	few		
Smell	no smell	no smell	no smell
Earthworm numbers	0		
Fungal hyphae	none		
Ped size	20 - 30	granular	
VESS/SubVESS	Sq3	Ssq4/5	
Depth to Water Table	Not encountered		

Table 7.4.17. Organic content of mineral and organic layers

Site 2, Area 6				
	LOI (%)	Organic Matter (%) (Dumas - calculated)	Suitability for Agriculture	Environmental Concern
Area 6.1: upper (0 - 170 mm)	3.2	1.9		

Table 7.4.18. Plant-available nutrients and pH of the mineral fractions

Site 2, Area 6					
		SAC	ADAS	Suitability for Agriculture	Environmental Concern
Area 6.1: upper (0 - 170 mm)	Available P (mg/l)	1.4(VL)	2.8(0)		
	Available K (mg/l)	76(M-)	70.5(1)		NA
	Available Mg (mg/l)	405(H)	282(5)		NA
	pH	7.3	7.9		

Na = Not Applicable

7.5 Vegetation analysis

The full results of the vegetation survey and analysis are provided in Appendix 5a [Full vegetation analysis (Site 1)] and photographs of the study areas are provided in Appendix 6a [Photographs of vegetation (Site 1). A brief summary is given below. The nature and suitability of vegetation present is summarised in Table 7.5.1.

Area 1 – Vegetation cover was dense across almost all of the area, with only a few, small bare patches (Appendix 6b, Plate 1). The health of the vegetation was generally good, although some of the grasses in some quadrats looked slightly pale and deficient in N. The area contained 17 plant species and the only abundant species was perennial ryegrass. Common bent, meadow foxtail, timothy and white clover were frequent throughout. Sown species include various cultivars of perennial ryegrass, coltsfoot, timothy and red and white clovers. The area contained some non-sown species but in general, this sward comprised mainly sown, agriculturally useful grassland species including forage grasses and clovers. The sward was also of high ecological value, since it contained a varied mix of grasses and other flowering plants. Most plants, including sown species were of good health and had a size and colour consistent with their textbook descriptions, although some areas of the sward were somewhat pale, indicating a likely slight shortage of N. The nature and suitability of vegetation present is summarised in this and other areas at Site 2 in Table 7.5.1.

Table 7.5.1. Summary of the vegetation present in the six study areas at Site 2

Area	Vegetation cover	Vegetation health	No. of species	Summary of species distribution in area as a whole	Grazing value[1]	Ecological value[2]
1	almost complete ground cover; relatively uniform height	mainly good	17	some weed species present but sown species predominant	v. good	v. good
2	almost complete ground cover, variable height	mainly good	21	as above	v. good	v. good
3	almost complete ground cover, variable height, sometimes tall and dense	good	29	some sown species but many weeds too, one of which was frequent	good	good
4	almost complete ground cover variable height, often tall and dense	good	28	some sown species but many weeds too, two of which were frequent	good	good
5	almost complete ground cover, variable height, occasionally tall and dense	good	26	as above	good	good
6	very sparse, mostly bare ground	poor	45	no sown species	v. poor	v. poor

[1]Grazing value scores:
- very (v) poor: few plants present and those present growing poorly and/of low forage value;
- poor = plants of poor health/growing poorly; species of low forage value predominate;
- moderate = plants relatively healthy; some species with forage value present
- good = plants healthy/growing well and sward contains at least 50% species of forage value;
- very (v.) good = plants healthy/growing well and sward contains at least 70% species of forage value;

[2]Ecological value scores:
- very (v) poor = very few species and/or a lot of bare soil;
- poor = relatively few species, and/or one or more weed species frequent or abundant (see DAFOR, Appendix 2) and/or some bare patches;
- moderate = most soil covered, moderate number of species but one or more weed species frequent or abundant;
- good = complete/almost complete soil cover, a reasonable range of flowering species from different families incl. grasses and non-grasses;
- very (v.) good: complete soil cover with a good range of flowering species from different families incl. grasses and non-grasses.

Area 2 - Vegetation cover was dense across almost all of the area, with only a few, small bare patches (Appendix 6b, Plate 2). The health of the vegetation appeared generally good, although some of the grasses in some quadrats looked slightly N deficient. The area contained 21 plant species and both perennial ryegrass and timothy were abundant. Common bent, creeping bent, yorkshire fog and white clover were frequent. Sown species include various cultivars of perennial ryegrass, cocksfoot, timothy and red and white clovers, all of which were present in the area. The area contained some non-sown species but in general, this sward comprised mainly sown, agriculturally useful grassland species including forage grasses and clovers. The sward was also of high ecological value, since it contained a varied mix of grasses and other flowering plants. Most plants, including sown species were of good health and had a size and colour consistent with their textbook descriptions, although some areas of the sward were somewhat pale, indicating a likely slight shortage of N.

Area 3 - The health of the vegetation was generally good, with little evidence of nutrient deficiency (Appendix 6b, Plate 3). The area contained 29 plant species. Sown species include various cultivars of perennial ryegrass, coltsfoot, timothy and red and white clovers. The frequency of sown species was lower in this area than in Areas 1 and 2. No species were dominant or abundant, but sheep's fescue, red fescue, yorkshire fog, perennial ryegrass, white clover and timothy were frequent across the area as a whole. The area contained several non-sown species which thrive in relatively poor (often acid) wet soils including rushes, field woodrush, marsh thistle, creeping buttercup, various species of sedge, tufted hair grass and yorkshire fog. The sward was of moderate ecological value, since it contained a varied mix of species with no dominant or abundant species. Most plants, including sown species were of good health and had a size and colour consistent with their textbook descriptions.

Area 4 - Vegetation cover was dense across almost all of the area, with a few, small bare patches (Appendix 6b, Plate 4). The health of the vegetation was generally good, with little evidence of nutrient deficiency. The area contained 28 plant species. Sown species include various cultivars of perennial ryegrass, cocksfoot, timothy and red and white clovers. As with Area 3, the frequency of sown species was lower in this area than in Areas 1 and 2. No species were dominant or abundant, but yorkshire fog, soft rush, perennial ryegrass and timothy were frequent across the area as a whole. The area contained several non-sown species which thrive in relatively poor (often acid) wet soils including soft rush, field woodrush, marsh thistle, creeping buttercup, various species of sedge, tufted hair grass and yorkshire fog. The sward was of moderate ecological value, since it contained a varied mix of species with no dominant or abundant species. Most plants, including sown species were of good health and had a size and colour consistent with their textbook descriptions.

Area 5 - Vegetation cover was dense across almost all of the area, with a few, small bare patches (Appendix 6b, Plate 5). The health of the vegetation appeared generally good, with little evidence of nutrient deficiency. The area contained 26 plant species. Sown species include various cultivars of perennial ryegrass, cocksfoot, timothy and red and white clovers. As with Areas 3 and 4, the frequency of sown species was lower in this area than in Areas 1 and 2. No species were dominant or abundant, but common bent, creeping bent, red fescue, yorkshire fog, soft rush and white clover were frequent across the area as a whole. The area contained several non-sown species which thrive in relatively poor, acid, wet soils including soft rush, field woodrush, marsh thistle, creeping buttercup, various species of sedge, tufted hair grass and yorkshire fog. The sward was of moderate ecological value, since it contained a varied mix of species with no dominant or abundant species. Most plants, including sown species were of good health and had a size and colour consistent with their textbook descriptions.

Area 6 - This area had not been deliberately sown and all 45 of the species present had arrived naturally (Appendix 6b, Plate 6). Vegetation cover was very sparse across most of the area and much of the soil was bare, though there were some patches where species typical of waste land were growing, albeit not vigorously. Only yorkshire fog and coltsfoot were abundant in this area, both of which thrive in poor soils and waste places. Plants in area six were generally very small in comparison with their textbook descriptions and often had a pale or purple colour, indicating general nutrient deficiency. The sward was of poor ecological value, since the topsoil substitute had very few plants growing on it.

7.6 Land Capability of Restored Area

Ignoring climate, the primary considerations for Land Classification for Agriculture (LCA) for Site 2 are: soil depth, stone content and drainage. In the areas represented by Locations 1 and 2, the LCA class would be a maximum of 5. As these area have been disked and could be ploughed in the future, this class is appropriate, but the very high stone content in the lower mineral layer would make a class of 5.1 unrealistic. The most suitable class would be 5.2 (which is described as “land moderately suited to reclamation and use as improved grassland”). This number is consistent with the historical LCA classification sections of the site.

The remainder of the site would currently be classed as LCA 5.2 however this will be reduced over time to a final classification of 5.3: *Land Marginally suited to reclamation and use as improved grassland* due to underlying drainage restrictions that have been temporarily alleviated by double digging process. Some concern about land form will also emerge as the buried layer of sewage sludge becomes more compacted and begins to anaerobically decay as this will lead to localised slumping which will further limit land management options.

Section of the Site 2, represented by location 1 and 2 have very limited potential for forestry due to shallow soils and stone content giving them Land Capability for Forestry Class of F6. The remainder of the site could be classed as F4 but if climate, elevation and soil fertility are considered then F5 would be a more suitable classification.

7.7 Conclusions on restoration success

The land forming has been completed to a high standard at Site 2, there were few surface rocks and stones, the land has been fenced, gated and livestock are now grazing on established swards. Given that the intended end use for the restored land there was agricultural grazing and the land is now functioning either very well or fairly well for that purpose, the restoration can be classed as being successful, at least to some extent. However, the soil profile investigations revealed problems with some of the soils on site. The degree to which the restoration can be classed as successful differs markedly between Areas 1 and 2 (where sludge was surface applied and disced in) and Areas 3, 4 and 5, where (information was provided from the land restoration contractor that) a double digging approach was used.

The success of restoration at the six study areas at Site 2 is summarised in Table 7.7.1. The information in the table is based on that set out and discussed in more detail in earlier parts of the document. The main observations on vegetation and soils were as follows:

1. Vegetation in Areas 1 and 2 was healthy and covered the soil surface well. The species mix was dominated by sown species of high forage value. Vegetation in Areas 3, 4 and 5 was also healthy and it also covered the soil surface well but although sown species of high forage value covered most of the ground surface, coarse weed species such as rushes, docks and weed grasses were frequent.

2. Vegetation was very sparse, pale and stunted on un-restored area at Site 2 (Area 6), and it contrasted strongly with the healthy, abundant relatively species-diverse swards in the restored areas. The nature of the vegetation found on the Area 6 reflected the extremely compact, nutrient-poor nature of the soil-forming material present.

Table 7.7.1. Summary of the environmental risk, agricultural potential, suitability of current vegetation cover and overall success of restoration at Site 2.

Area	Environmental risk (ER)[1]	Agricultural potential (AP)[2]	Current vegetation cover suitable for[3]		Success of restoration (SRest)[4]	Comments
			Agriculture	Ecology		
1	Low	very good	very good	very good	very good	• ER low due to the acceptable P status and acceptable soil PTE content. • AP very good due to soil P and K status being at or near target, evidence of soil structure development and earthworm activity. Soil pH/Mg status higher than ideal; SOM lower than ideal. • SRest very good due to the above. Ongoing management will be required to maintain and further improve soil quality.
2	Low	very good	very good	very good	very good	• ER low due to low P status and acceptable soil PTE content. • AP very good due to evidence of soil structure development and earthworm activity. Soil pH on target, soil P/K status, SOM lower than ideal, soil Mg status higher than ideal. • SRest very good due to the above. Ongoing management will be required to maintain and further improve soil quality.
3	High	moderate	good	moderate	poor	• ER high due to presence of (RAN/P-rich) buried sludge layer (280-550 mm depth). • AP moderate. Current performance of vegetation acceptable but risk of subsidence high. Some compaction, topsoil very acid (4.3-4.7) and L/VL plant-available P and K in topsoil. • SRest poor due to above and because nutrients and organic matter buried below useful depth.
4	High	moderate	good	moderate	poor	• ER high due to presence of (RAN/P-rich) buried sludge layer (530-700 mm depth). • AP moderate. Current performance of vegetation acceptable but risk of subsidence high. Some compaction, topsoil very acid (4.7-5.4) and L/VL plant-available P and K in topsoil. • SRest poor due to above and because nutrients and organic matter buried below useful depth.
5	High	moderate	good	moderate	poor	• ER high due to presence of (RAN/P-rich) buried sludge layer (220-350 mm depth). • AP moderate. Current performance of vegetation acceptable but risk of subsidence high. Some compaction, topsoil very acid (4.9-5.2) and M/H P plant-available P and VL/L K in topsoil. • SRest poor due to above and because K and a lot of organic matter buried below useful depth.
6	Low	very poor	very poor	very poor	not restored	• Area was not restored • ER low because no nutrients or sludge have been applied and soil low in RAN/available P. • AP very poor due to compaction, relatively low topsoil OM content and VL plant-available P/K.

[1]**Environmental risk:** low, moderate or high;
[2]**Agricultural potential (given the potential LCA class for this area):** very poor, poor, moderate, good or very good, depending on the soil physical and chemical characteristics;
[3]**Suitability of current vegetation cover:** for: agriculture (based on amount and health of vegetation present and forage value of species present) and ecology (based on species diversity and presence of useful species);
[4]**Success of restoration:** very poor, poor, moderate, good or very good (an assessment which depends on the environmental risk, the agricultural potential and current vegetation of the area).
NB: Further details for each area are provided under "Comments above" and in sections 6.4 and 7.4).

3. To summarise, the restoration in Areas 1 and 2 was highly successful in terms of soil improvement, vegetation establishment and vegetation growth. Soil organic matter content and soil nutrient status have both increased through the incorporation of surface-applied sewage sludge by discing. There was also evidence that serious compaction present in Area 6 below 170 mm (and apparently present across much of the site after land forming but before restoration) was no longer present in Areas 1 and 2, so the relief of compaction by deep ripping must have been successful. Areas 1 and 2 had limitations in terms of rooting depth but the potential rooting depth of 300 mm which has been achieved there was sufficient to support the intended end usage. Discing effectively restricted the sludge to the upper 300 mm of soil profile where the maximum benefits from the use of sludge could be realised.

4. The situation for Areas 3, 4 and 5 was confusing, since there was an additional mineral fraction present that was not present at the control site (Area 6) or Areas 1 and 2. This additional mineral fraction was characterised by a low pH and formed the upper layer (Layer 1) at Areas 3, 4 and 5. Peat was also identified as being present in the soil in these areas, but the relatively low SOM content in the upper soil layer indicated that the peat was not present in sufficient quantity to impact pH to this degree and sewage sludge application would also be an unlikely source of acidity. It is likely that the mineral fraction present in Areas 3, 4 and 5 was the original topsoil that was spread as the surface layer during initial site restoration works completed prior to land restoration with sludge.

5. The continued presence of a discrete layer or deposit of sewage sludge within the soil profile in Areas 3, 4 and 5 was a concern when evaluating the environmental risk and the degree of success from the restoration. At Areas 3 and 4, the remaining sludge layers were between 350 - 400 mm thick and occurred at depths below the rooting potential for the target species used for restoration. At Area 5 the sludge layer started at a depth of ~ 200 mm and was limited to a maximum thickness of 120 mm. The continued presence of these sludge layers 4 years after completion of restoration is having a negative impact on plant growth, because it was clear (during soil investigations) that roots were not growing into or it.

6. Based on a wet bulk density of 1.3 kg/l and using the measured thickness of the remaining sewage sludge layer at study Areas 3,4 and 5, the amounts of unincorporated sludge still remaining within the soil profile more than accounts for the stated application rate of 400 t/ha. Based on this, the low P status in the upper layers at Area 3 and 4, coupled with the above observation (in point 4 above) on acidity it can be assumed that the upper soil layers in Areas 3, 4 and 5 were topsoils that were used in the restoration prior to the incorporation of sewage sludge. The plant-available P concentrations in Area 5 were higher than those in Areas 3 and 4 and may indicate the successful incorporation of sewage sludge in the upper profile of the soils in Area 5. However, if this was the case then the application rate of sewage sludge must have been well above 400 t/ha (the rate stated in the Paragraph 9 exemption) given how much sludge is clearly still remaining unincorporated within the soil profile. Alternatively, the higher plant-available P concentrations in Area 5 may simply have resulted from the use of more nutrient-rich topsoil in the restoration before the sludge was applied.

7. To summarise, the restoration in Areas 3, 4 and 5 has only been partially successful. No agricultural benefit can be attributed to use of sewage sludge in the restoration of Areas 3, 4 and 5 apart from an increase in plant-available P in the topsoil in Area 5. Assuming the stated application sludge (400 t/ha) is accurate, then this full amount can be more than accounted for by the unincorporated sludge layers that remain within the soil profile in these areas. Due to the depth of the sludge layers present, the nutrients and organic matter in the sludge are not accessible to the plants growing on the site. Furthermore, there is a potential risk of nutrients (particularly P) leaching from the sludge into surrounding watercourses over time. There is also a risk of topsoil movement (subsidence) which could lead to the development of hollows, sunken areas and even landslips as the sludge breaks down anaerobically over time.

8 Discussion and recommendations for ensuring the success of restorations

The recommendations set out below have been based mainly on findings from this project. However, they have been informed from experiences gained when working with restorations on other sites in Scotland and beyond, and from seeing opportunities in practice to improve restoration outcomes for the future. The recommendations are set out under eight headings. The background to each recommendation is discussed in normal text and the recommendations are in blue italics.

It is understood that most of the recommendations outlined below could be partly or fully implemented under the current WMLE regulation, but some could only be brought in once the Integrated Authorization Framework (IAF) has been completely implemented, by which time restoration work will likely be under site-based permits. The suggested timescales for implementation are noted below. For those recommendations which could be implemented now, required changes would be made at the renewal stage and it must be emphasised here that the recommendations are intended for current WMLEs and not for past restorations sites (for which the WMLEs have expired).

Waste Management Licence Exemption (Paragraph 9) [or subsequent equivalent] application

It was extremely difficult to work out what application rates were used on which parts of Site 1. The paperwork available was incomplete and contained some contradictions. There was clear evidence (when walking the site) that some areas which could have been spread were not, and some areas for which there were no records of spreading had been spread. Hand held GPSs and mapping software are now easily available and relatively inexpensive and if used, could help SEPA to track work being done on restoration sites.

1. *SEPA could insist on good quality maps, since evidence suggests that some currently submitted to SEPA are of poor quality. For example, simple maps based on GPS data to show the site boundary, the position of existing and planned watercourses and water bodies and the boundaries of reasonably accurate planned spreading areas (each of no more than 10 ha). Each spreading area should be based around a single OS 10-figure grid reference, or set between several OS 10-figure grid reference points. If spreading areas are better defined and mapped in the initial application to SEPA, then it will be much easier to track the progress of restorations on site, to find the target areas when soil sampling (and this applies to restoration companies as well as SEPA) and to identify problems if they occur. SEPA should also insist that waste return data specify which (named or numbered) areas, as defined on the initial map, were spread with defined tonnages of particular wastes or waste mixtures in which months of the exemption period. This recommendation could be implemented now, under the current regulations.*

There was little evidence at Site 1 that any effort had been made to turn the land into useful agricultural land, to prepare any part of the land for trees of any type, or to optimise its ecological value. At Site 2, on the other hand, it was clear that the restoration company was keen to secure a tenant farmer as soon as possible after restoration. The land was fenced and gated and livestock were introduced as soon as a suitable stand-off period was up (given that sludge had been used during restoration). There is currently too much leeway in the regulations for restoration companies to apply sludge, then disappear from the site, without ensuring that the proposed end use for the site is achieved.

2. *SEPA could insist that plans submitted for restoration have to be appropriately detailed in the Para 9 (or subsequent equivalent) application and ideally should reflect a chosen end use. For example, if the end use is agricultural grazing, then there must be a commitment to achieve listed target outcomes, such as "engage a tenant" and/or to "ensure that the ground surface is safe for livestock and will be fenced and gated". If, for example trees are planned, then appropriate guidance should be sought as to creation of suitable soil chemical and physical properties. For example, Forest Enterprise Scotland are currently updating their guidance, which they are likely to insist is followed if they are to provide grants for tree establishment on restored sites. It is understood that under the current planning system, it is possible for restoration companies to plan and complete a restoration with no particular end use in mind. In that*

case, they should ensure that the restored land is suitable for production of low intensity grassland (a low level of fertility is required to kick-start soil structure formation, but there would be no justification for high application rates of organic materials if there were no guarantee that crops with high nutrient requirements would be planted or sown). All sites should be required to plans for post-restoration testing and management (see below). Although this recommendation could be implemented now, under the current regulations, it is recognised that it would be difficult (under the current regulations) for SEPA to take action if the restoration company fails to carry out their stated plans. Given that the land restoration market in Scotland is dominated by relatively few, large players, each operating over the long term on many sites, perhaps the greatest chance to exert control over the quality of land restoration companies is to reward responsible operators (who regularly demonstrate their commitment to effective, safe restorations) by continuing to approve their plans, and to refuse applications from (or at least place restrictions on) operators which have failed to achieve effective, safe restorations.

Final land-forming prior to final restoration

Whilst there was clear evidence that the land forming at Site 2 had been completed to a high standard (for example the land looked similar in shape to surrounding land and there were no excessively steep slopes), that at Site 1 was extremely poor in places. Land should have been effectively re-shaped before topsoil amendment with organic materials, OR there must be a detailed commitment in the Para 9 (or subsequent equivalent) application to do so.

3. *For many sites (particularly those close to sensitive receptors, those to which particularly high RAN or odorous materials are intended for application and larger sites, such as those greater than 100 ha in size), it is recommended that SEPA visit the site (before awarding a Para 9 (or subsequent equivalent)), with the restoration company to view the site and determine whether further land forming will be required to remove or alter potentially hazardous areas. During this visit SEPA staff can also have a brief look at the soil surface and vegetation and the nature of vegetation and land use on surrounding land. They can assess the risks and requirements of the site, bearing in mind the restoration company's plans for it. This will help them assess subsequent Para 9 (or equivalent) applications for the site. SEPA staff should take care, however, not to over-interpret what they see and recognise that detailed soil profile investigations including deep excavations to at least 1 m depth should be undertaken in order to understand the need for compaction relief and organic materials amendments. Ideally the restoration companies should be doing such investigations, but it may be necessary for SEPA to insist that they do, and that they employ suitably skilled staff to help them interpret results and define appropriate restoration techniques where they cannot do so themselves. It may be beneficial for SEPA to better define the number of soil samples required in order to obtain representative results, and parameters to be tested. It may be necessary for SEPA to see the results of soil physical investigations if they bear direct relevance to Para 9 (or equivalent) applications or if problems arise during or after the restoration. It is recognised that the above will come at a cost and charges for WMLEs should increase in order to reflect the extra work required by SEPA staff. Given that the charges for the various exemptions are currently fixed, there is limited scope for SEPA to conduct more detailed soil profile investigations (where required) until the new IAF is implemented.*
4. *Where it is possible for SEPA to visit a site prior to registering a WMLE, and evidence is found of inappropriate landforms on site (e.g. excessively steep slopes) or large quantities of rubbish on site, SEPA should insist on seeing evidence that these have been removed before organic materials applications can commence. This recommendation could be implemented now, under the current regulations, but it is recognised that the costs of WMLEs must increase to make such visits possible for all planned restoration sites.*
5. *A robust matrix of criteria should to be established that provides an understanding and sets targets for the evaluation of analytical data for pre and post restoration assessments. This should include key determinates such as organic content and available plant nutrients and provide a similar evaluation process to the traffic light system used in this report. The matrix should be capable of identifying key indicators that highlight the need for restoration with waste materials and provide a system to interpret post restoration analysis results in order to determine that the restoration was successful and represents no environmental risk. Consideration should be given to extending this to the use of non-*

analytical criteria in the pre-evaluation proposed that can assess the potential of site to achieve the target end usage. Criteria such as "land pattern" are defined under the Land Capability Classification for Agriculture can be an effective means of ensuring that a site has the inherent potential to achieve the targets for restoration. Other criteria such as potential rooting depth, VESS scores and drainage class are all well-established assessments that can be employed to determine the suitability and success of the restoration process. "

Compaction relief

The authors have found evidence from all over the UK that soil compaction is a major reason for failure of restoration schemes, particularly those involving trees. Site 1 was no exception. A large amount of public and private money has been wasted in Scotland alone, through grant schemes for failed tree planting schemes on restoration sites. Compaction was a feature in soils at both Sites 1 and 2. However, there was evidence that rooting and natural soil structure-forming processes were winning the battle over compaction at Site 2, because compaction relief had been sufficient (particularly in Areas 1 and 2) to allow plants and soil animals to begin to colonise the soil effectively.

6. *SEPA should insist that the degree of compaction on restoration sites is investigated, documented and ameliorated using appropriate methods. These methods are likely to involve deep ripping (to at least 50 cm and up to 1 m depth where appropriate machinery permits) in at least one direction. In some cases, where soil profiles have to be created from scratch, they can be loosened or ripped in two or more stages as subsequent layers are added. Subsoils and topsoils can also be placed using the loose tipping method, so compaction is avoided in the first place (Defra, 2009: Construction Code of Practice for the Sustainable Use of Soils on Construction Sites). Compaction relief is particularly important where trees are to be planted. It may be necessary to insist on photographs of the machinery during operation and or photographs of soil profiles excavated following restoration. This recommendation could be implemented now, under the current regulations.*

Application rates

There was some evidence, mainly from Site 1 that sewage sludge application rates may have been considerably higher than those which had been requested in the Para 9 application. SEPA does not support excessively high application rates of sewage sludge being applied to land (and that has to be a good thing for the environment), but some land restoration companies are deeply concerned over the seeming continued downward pressure on permitted application rates by the Regulator. Many feel, with some justification, that if application rates are set too low, then insufficient organic matter will be applied to soils to allow structure-formation to begin. Whilst it might be better from a pollution prevention point of view to have repeated lower tonnages applied to soil over the years (as is common practice in agriculture) rather than one high application, this is simply not practical in land restoration. The companies involved need (financially) to apply organic materials once, finish the job and move onto the next site.

There is a clear need for further work to determine the optimum rates for organic materials applications in restoration, given the challenging soils to which they are applied. The optimum application rate will depend not only on the existing soil materials on the site but also on the intended end use, the materials in question and the intended application and incorporation methods. However, some land restoration companies also feel that SEPA must acknowledge the fact that waste organic materials are the financial engine which drives restoration. If permitted application rates are set unnecessarily too low, then restoration, which is almost always a commercial activity, will simply cease. The priority is to ensure that organic materials are used safely and with agricultural or ecological benefit, whilst still ensuring that successful restorations are financially viable all over Scotland.

It is recognised that it is difficult for SEPA to keep track of the volumes of organic materials being used in particular parts of restoration sites. That is, a maximum tonnage is typically permitted for application to a defined area (which can be well in excess of 100 ha). Although a maximum application rate is also permitted, there is evidence that this rate has been exceeded on some parts of some sites. At present, it is only possible to detect serious breaches of the rules over entire sites. The following approaches are suggested:

7. *Permit only those application rates which are likely to help ensure restoration success without serious risk to the environment. Setting those rates is difficult, given that all sites and soil-forming materials are different and given that different restoration professionals (including soils specialists) argue over the most appropriate rates. This could be done now, under the current regulations.*
8. *It is recommended that a formal "completion of restoration" report be required for larger sites that would include, in part, a fully audited report on the type, source and amount of sewage sludge used. It is recognised that this recommendation could only be implemented under the new IAF. It is recommended that SEPA request that each site is divided into areas of ≤ 10 ha for soil testing, then tonnages applied to each area should be recorded, along with approximate application dates.*
9. *If serious breaches of regulation are suspected, then it should be possible to request copies of all the weighbridge tickets for all wastes accepted onto a restoration site. If restoration companies knew that the Regulator may request these, then they may be reluctant to apply considerably more sludge than that permitted under their Para 9 WMLE (or equivalent). However, it is easy for irresponsible operators to hide some of their weighbridge tickets. This recommendation could be implemented now, under the current regulations.*
10. *A further possibility under the new IAF would be to appoint an independent supervisor to visit restoration sites during ongoing work to audit the process. They might examine documentation such as weighbridge tickets and could visit areas where sludge was being applied. Given the need to severely restrict access to visitors based on health and safety grounds, it would still be perfectly possible for irresponsible operators to hide bad practice and show only the parts of the operation that suited them, hence this approach probably has limited value. The cost of this would have to be borne by restoration companies, which is likely to prove unpopular with them.*

It is particularly important to set application rates in relation to the intended end use. Land restoration companies (such as the one operating at Site 1) often mention the creation of species-rich grassland in their applications, and then go ahead and apply hundreds of tonnes of sludge per hectare, thus creating a nutrient-rich topsoil completely inappropriate for creation of such grassland.

11. *SEPA must continue to question the use of high tonnages of sludge in the creation of species-rich grassland. Alternative organic materials should be sought, or mixtures created based only partly on sludge. The aim should primarily be to increase the carbon:nitrogen ratio of mixtures applied, and to reduce the phosphate content. SEPA should ensure that restoration companies are aware of, and understand the relevant parts of available guidance (e.g. "Guidance on Suitable Organic Materials Applications for Land Restoration and Improvement" by ADAS and Earthcare Technical, 2015) and no doubt SEPA already point this out when insisting that intended application rates are reduced. This recommendation could be implemented now, under the current regulations.*
12. *It would be a good idea to set (and publicise) loading rate limits on key parameters, such as total phosphate loading, total RAN and total PTEs in a single application. It is recognised that a range of limits are likely for parameters such as phosphate, RAN and soil organic matter depending on the intended end use for the soil in question. It is also important to bear in mind that the soil chemical properties of the finished topsoil are important too, and different loading rates may be required to reach the same end point for different soil types. This is a complex area and there is a need to keep any advice simple, but it would be helpful to restoration companies to have some guidance as to what is expected of them. This recommendation could be implemented now, under the current regulations.*
13. *Some restoration companies are now modelling the likely physical and chemical properties of the finished topsoil in advance of applying organic materials. They then choose appropriate application rates, complete the restoration and test the finished topsoils several months down the line to determine whether they have achieved the intended outcome. They are gradually improving their practices in order to better be able to predict the nature of restored soils following application of different types of amendment. This is perhaps a ground breaking approach, and a fairly costly one during development, but SEPA could consider recommending a similar approach to all restoration companies now, since there is increasing evidence that it is leading to improved restoration outcomes.*

It is important to check that land restoration companies are applying the permitted rates of organic materials. It is likely to be much too expensive for SEPA to go onto restoration sites routinely to conduct the sort of detailed soil profile investigations and testing which were done in this project. However,

14. *When IAF is implemented, SEPA could insist on post-restoration soil tests for areas of no more than 10 ha. These tests should be for a minimum of routine analysis (pH and extractable P, K, Mg), soil organic matter and soil PTE content. Good agricultural practice should dictate that any responsible land manager would conduct these tests as a matter of course before taking on management of a new piece of land, so the test results would not only help SEPA and the restoration company to understand whether restoration had been successful, but would also help any new tenant or buyer assess the quality of the land he was about to take on. Tests may need to be more comprehensive if land is to be used for forestry. For example assessment of stone content and soil profile investigations to evaluate compaction and/or the degree of compaction relief.*
15. *SEPA should continue to investigate restoration sites where problems have obviously occurred (e.g. pollution of surrounding water courses) by digging pits (as conducted in this project) and taking a series of samples from deep within the soil profile, where there is clear evidence of environmental pollution from a site or clear evidence of a failed restoration (such as tree death or poor vegetation growth). Through observations and by testing and calculations, it can be proved that inappropriate tonnages of organic materials have been applied in an inappropriate way. It may be possible to fine the companies responsible and also to work more closely with these particular companies in future when they submit plans, to prevent them making the same mistakes in future. It is understood (from discussions with SEPA staff and those living and working in the vicinity of restoration sites) very few problems have occurred in the land and watercourses surrounding restored sites. Most problems with restored sites concern the poor quality of the topsoils created and the inability of soils to support useful vegetation. It is recognised that SEPA have no reason to investigate a failed restoration unless there are obvious pollution problems on and around it. The best chance to prevent failed restorations in future is therefore for SEPA to insist on appropriate methods for restoration which fit the site and the end use. This can be achieved by working with restoration companies now, to ensure that the Certificates of Agricultural Benefit contain sufficient, appropriate detail.*

Permitted organic materials

Sewage sludges are not necessarily the best type of organic material to be used in land restoration. Most soil-forming materials on most restoration sites primarily need organic matter to help kick-start soil structure formation. They also need sufficient slow-release nutrients to satisfy the needs of developing vegetation, but not so much that environmental pollution might result, which is clearly a risk at Site 1 and in parts of Site 2. The ideal organic material for this purpose might be green compost rather than sewage sludge, which is often wetter than ideal and often too rich in both phosphate and RAN. However, compost is usually expensive and difficult to get hold of, whereas accepting sewage sludge onto restoration sites attracts a much-needed gate fee. Many restoration sites have access to alternatives to sewage sludge, which could be mixed with the sludge to improve its properties or applied along with the sludge and cultivated in to topsoils, with benefit.

16. *Where appropriate, SEPA should consider encouraging restoration companies to seek high C, low P, low RAN alternatives to sewage sludge, which could be applied to land along with the sludge, or in blends mixed prior to application. By using alternatives to sludge along with the sludge, it could be possible to maximise the quality of finished topsoils. Such materials might include paper crumble, clean water sludges and waste wood fines.*

Given the impending Scottish Government ban on organic materials to landfill, a range of novel materials, some of which are useful alternatives to sewage sludge, may come on to the market which have potential to be useful in land restoration.

17. *If SEPA are considering allowing novel materials to be used under the proposed new permitting regime (IAF), care should be taken to ensure that the companies considering such wastes conduct detailed analysis of both potential harmful elements and compounds and beneficial properties, then interpret the results with care, so that they understand the implications of using the materials in question.*

Application methods

There is clear evidence from this project, and from elsewhere on a range of other restoration sites, that surface cultivations (top 30 cm) of surface applied sludge result in a better restoration outcome than where sludge is placed in a layer beneath a layer of mineral soil. Topsoil structure development happens fastest where there is good mixing between the organic materials applied and soil mineral material.

Burial of anything other than a shallow (e.g. 10 cm) sludge layer is (in the authors' opinion) never good practice, and will always result in slower development of soil structure than where the organic material is cultivated in. However, in situations where stones are prevalent, some restoration companies feel that burial of sludge in layers is the only option. They also feel (probably with good reason) that burial of the sludge results in faster odour mitigation than where sludge is cultivated into the surface. Where sludge layers are buried below 30 cm with minimal incorporation into mineral material, the outcome tends to be particularly poor. The deeper the sludge layer the poorer the restoration outcome. Plant roots and soil macrofauna, which are key to soil structure development, will not move into the sludge layer and the developing vegetation tends to have little or no access to the nutrients with it. There is a high risk of subsidence of topsoil over time, and leaching of nutrients, particularly phosphate and nitrate, into surrounding watercourses.

18. *SEPA should consider insisting on surface application of sludges followed by surface cultivations where possible, though it is acknowledged that this may increase odour problems during application where high odour materials are being applied. This recommendation could be implemented now, under the current regulations.*
19. *SEPA should prohibit the burial of sludge with a layer thicker than 60 mm and should prohibit burial of sludge where the lower boundary of the sludge layer is deeper than 300 cm, since there is very little justification for the practice.*

Recording and monitoring of work done

No records existed of what actually happened at Site 1 in terms of land restoration and the organic materials applied. It was easier to find information on what had happened at Site 2, although the records of what had happened did not always match what the evidence suggested had happened in practice. No post-restoration testing of the soils at Site 1 had happened and no soil test results were available from Site 2 either. If SEPA are to ensure that restorations are successful, then some degree of monitoring and recording of restoration progress and the properties of finished topsoils are essential. The current returns required from SEPA only contain (apparent) records of the organic materials applied, they do not require the operator to provide evidence of exactly what tonnages were applied to each part of the designated site, and do not require test data from finished topsoils.

20. *SEPA could ask for more detail in renewal applications and/or in returns, where differing application rates were used in the area covered by a WML exemption (i.e. where lower or higher rates than those permitted were applied). This recommendation could be implemented now, under the current regulations.*
21. *SEPA could consider requesting that finished topsoils should be tested for key parameters of environmental concern and agricultural benefit within a year of placement. The soil samples should be clearly labelled as from areas denoted on a good quality map (as outlined in the recommendations under Waste Management Licence Exemption (Paragraph 9) [or subsequent equivalent] application above). This recommendation could be implemented now, under the current regulations for renewals only. It should be considered for inclusion in future permits under the integrated authorisation framework.*

Post restoration management

A key reason for failure of restoration at Site 1 was the lack of post-restoration management. The failure of many other Scottish restoration sites can be at least partly attributed to the same reason. Post restoration management at Site 2 has been exceptionally good in Areas 1 and 2 (by both the restoration company and the new farmer tenant), and this has ensured the best possible outcome for these two areas. Post restoration management has also been good at Areas 3, 4 and 5 at Site 2, although further weed control is clearly required. It remains to be seen whether further groundworks will be required to address potential subsidence at these areas.

There is a clear need for post-restoration management at all restoration sites, without exception.

22. *When the new Integrated Authorisation Framework is implemented, SEPA could insist on a clear, detailed post-restoration management strategy prior to registering Para 9s (or subsequent equivalents). This is likely to mean that restoration companies must either retain responsibility for a site for longer than they currently do (1, 2 or possibly up to 5 years post-restoration) or should officially hand over responsibility for compliance to a new owner or tenant.*
23. *Post restoration management is likely to include some or all of the following:*
    - *Soil testing and interpretation of results (as outlined in "Recording and monitoring of work done" above);*
    - *Remedial application of lime or fertiliser/organic materials as required;*
    - *Fencing and gating;*
    - *Removal of surface stones (these sometimes become apparent post–restoration);*
    - *Provision and maintenance of paths and access tracks;*
    - *Weed control;*
    - *Topping or grazing of grass;*
    - *Installation of drains where drainage issues become apparent;*
    - *Additional compaction relief (subsoiling or aeration of the topsoil to some extent);*
    - *Mitigation of pollution or soil erosion where issues become apparent;*
    - *Re-sowing of failed swards;*
    - *Gapping up to replace trees which have failed to establish.*
24. *SEPA could monitor the implementation of post-restoration measures. Only those companies which do an acceptable job should continue to be awarded permits to restore land.*

Need for clear guidance on land restoration techniques

Those involved in land restoration currently feel that SEPA's requirements have changed over the last couple of years and they are looking for clear guidance as to what is acceptable and what is not, to that end:

25. *This is likely to mean issuing a new set of guidelines, or more likely updating the current guidance. Simple guidance should define the information required in a site restoration plan, the need for pre-restoration land-forming, pre-restoration soil investigations, justification for proposed application rates, post-restoration management and post-restoration soil testing (see post restoration testing and management above). The guidelines should also include information on acceptable application rates, acceptable loading rates for key parameters (such as phosphate, RAN and PTEs) and acceptable target values for key soil parameters (such as pH, plant-available nutrients and SOM content). This recommendation could be implemented now, under the current regulations.*
26. *SEPA should continue to attempt to apply a fair, consistent approach to what is acceptable in terms of application rates and methods used in land restoration across all of Scotland. Some land restoration companies are saying that this is not currently the case.*

Funding of future restoration permits and compliance monitoring

It is clear that if the degree of success in Scottish restoration schemes is to be improved, then further site-based work and increased monitoring from SEPA will be required. It is widely understood that is likely to mean that permitting costs for operators will increase in a move towards full cost recovery. In an effort to optimise the use of scarce resources (staff and funding):

27. *SEPA should continue to concentrate resources (in terms of site monitoring and appraisal of data from land restoration companies and also enforcement) on those operators who continue to disobey the regulations, continue to fail to demonstrate good practice and fail to achieve successful restorations.*
28. *Provided there is adequate evidence to support this, SEPA could consider reducing the burden of site visits to land restoration companies which consistently demonstrate compliance with regulations over time, and show good restoration practice, achieve successful restorations and regularly provide quick responses to requests for information. This recommendation could be implemented from now on.*

9 Glossary

Aggregate - A group of soil particles that binds to each other more strongly than to adjacent soil particles.

Bulk density – Bulk density of soil is the weight of soil per unit volume. It can be measured in various ways. Laboratory bulk density (often defined simply as dry bulk density) is normally done on dried, milled soil (and that is what was quoted for soils tested in this report). The value for laboratory bulk density depends on the amount of sand, silt, clay, small stones and organic matter the soil, but it gives no indication of compaction and pore space in the soil as it was in the field. Soil bulk density can also be measured in wet or dry intact cores taken directly from the field. The value obtained from this method takes into account the amount of pore space and the degree of compaction present in soil in the field. Soil bulk density in intact cores was not measured in this project.

Consistence – The combination of properties of soil material that determine its resistance to crushing and its ability to be moulded or changed in shape. Terms including: loose, friable, firm, soft, plastic and sticky describe soil consistence.

Consistency – The interaction of adhesive and cohesive forces within a soil at various moisture contents as expressed by the relative ease with which the soil can be deformed or ruptured.

DAFOR scale – This records the relative abundance of species found in a quadrat or study area as follows: D = Dominant; A = Abundant, F = Frequent, O = Occasional, R = Rare. Each species present in a study area or quadrat was identified and listed. In order to use or interpret letters from the scale correctly, it is important to read the full details on the system (Appendix 2).

Land Classification for Agriculture (LCA) – A system used to rank land on the basis of its potential productivity and cropping flexibility. The classification is determined by the extent to which the physical characteristics of the land (soil, climate and relief) impose long-term restrictions on its use. The Scottish classification system differs from that used in England and Wales. It is a seven class system, with four of the classes being sub-divided into two. Class 1 represents land that has the highest potential flexibility of use, whereas Class 7 land is of very limited agricultural value. Table 9.1 defines the Scottish LCA classes and a full description of the system can be found on the James Hutton Institute website at: http://www.hutton.ac.uk/sites/default/files/files/soils/lca_leaflet_hutton.pdf.

Land Classification for Forestry (LCF) - A system used to rank land on the basis of its potential to grow trees. As with the LCA, the classification is determined by the extent to which the physical characteristics of the land (soil, climate and relief) impose long-term restrictions on its use. Again, the Scottish classification system has seven classes which differ from those used in England and Wales. Class 1 represents land that has the highest potential flexibility of use for tree crops, whereas Class 7 land is unsuitable for producing tree crops. Table 9.2 defines the Scottish LCF classes and a full description of the system can be found on the Scotland's Soils website at: http://soils.environment.gov.scot/maps/national-scale-land-capability-for-forestry/.

Table 9.1. Definition of Scottish LCA classes	
LCA class	Definition of land
Land capable of supporting arable agriculture	
1	Land is capable of producing a very wide range of crops and there are no, or only very minor physical limitations affecting agricultural use.
2	Land is capable of producing a wide range of crops, there are minor physical limitations affecting agricultural use and the land is highly productive.
3.1	Land is capable of producing a moderate range of crops with high yields of cereals and grass; potatoes and other vegetables are grown.
Land capable of supporting mixed agriculture	
3.2	Land is capable of producing a moderate range of crops with an increasing trend towards grass within the rotation.
4.1	Land is capable of producing a narrow range of crops; enterprises are based primarily on grassland with short arable breaks.
4.2	Land is primarily suited to grassland with some limited potential for other crops (barley, oats and forage crops).
Land capable of supporting improved grassland	
5.1	Land is capable of use as improved grassland; establishment of the sward and its maintenance present few difficulties.
5.2	Land is capable of use as improved grassland; sward establishment presents no difficulties but physical limitations can cause maintenance problems.
5.3	Land is capable of use as improved grassland and although the sward can be established, deterioration can be rapid due to a range of factors.
Land capable of supporting only rough grazing	
6.1	Land is capable of only rough grazing due to intractable physical limitations; the semi-natural vegetation provides grazing of high value.
6.2	Land is capable of only rough grazing due to intractable physical limitations; the semi-natural vegetation provides grazing of moderate value.
6.3	Land is capable of only rough grazing due to intractable physical limitations; the semi-natural vegetation provides grazing of low value.
7	Land is of very limited agricultural value and use is restricted to very poor rough grazing.

Table 9.2 Definition of Scottish LCF classes	
LCF class	Definition of land
F1	Land with excellent flexibility for the growth and management of tree crops.
F2	Land with very good flexibility for the growth and management of tree crops.
F3	Land with good flexibility for the growth and management of tree crops.
F4	Land with moderate flexibility for the growth and management of tree crops.
F5	Land with limited flexibility for the growth and management of tree crops.
F6	Land with very limited flexibility for the growth and management of tree crops.
F7	Land unsuitable for producing tree crops.

Legume – A plant from the pea family which can fix its own nitrogen from the soil air.

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

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

P – see Phosphorus

Ped – A unit of soil structure, such as an aggregate, crumb, prism, block or granule, formed by natural processes (in contrast to a clod, which is formed artificially, e.g. through the action of man).

Phosphorus (or P) – An essential plant nutrient element which is required in relatively large quantities by plants. It is rarely present in nature in its elemental form and tends to exist in association with oxygen, when it is known as phosphate. For that reason, and according to convention, the results of tests to determine the phosphorus content of bagged fertilisers and organic fertilisers such as sewage sludges are presented as phosphate rather than phosphorus. It is important to understand the units in which laboratory test results or fertiliser nutrient content are being presented since the phosphate molecule is 2.29 times heavier than the phosphorus atom. Soil analysis results are usually presented in mg of phosphorus/l of soil. However, fertiliser recommendations are almost always given in units of phosphate per unit area (e.g. kg/ha). Unfortunately the abbreviation "P" is routinely used for both phosphorus and phosphate in the literature and verbally by fertiliser advisors and farmers, which can result in occasional confusion. The abbreviation "P" is usually taken to mean phosphorus when talking about phosphorus content in soil or water or phosphorus status/index and it is usually taken to mean phosphate when talking about the amount of phosphate in inorganic or organic fertilisers.

Plant-available phosphorus (or more correctly, plant extractable phosphorus) is tested using many different methods, but those most often used in the UK include extractions made with "Olsen's P" reagent (as used by most labs in England and Wales) and "Modified Morgan's" extractant (as used by the SAC Analytical Lab and developed in Scotland for use on Scottish soils). Although it was primarily thought that there was a good system for comparing results obtained using the two methods (e.g. an Olsen's P index of 1 was broadly equivalent to a Scottish soil phosphorus status of low; an Olsen's P index of 2 was broadly equivalent to a Scottish soil phosphorus status of moderate, etc.), several experts now agree that in fact the use of Olsen's P to determine extractable phosphorus concentrations in Scottish soils can overestimate plant availability of phosphorus.

Plastic limit – The plastic limit of a soil is the moisture content, expressed as a percentage of the weight of the oven-dry soil, at the boundary between the plastic and semisolid states of consistency. It is the moisture content at which a soil will just begin to crumble when rolled into a 3 mm thread. The plastic limit is one of the three "Atterberg limits" which strictly speaking only apply to fine-grained soils (i.e. those that contain mainly silt and clay). The other two limits are the "shrinkage limit" (the water content where further loss of moisture will not result in any more volume reduction) and the "liquid limit" (conceptually defined as the water content at which the behavior of a clayey soil changes from plastic to liquid.).

RAN - (see readily available nitrogen)

Readily available nitrogen (or RAN) – the forms of nitrogen which are readily lost (through leaching or volatilisation) or readily taken up by plant roots. The two main forms are nitrate (NO_3^-) and ammonium (NH_4^+).

Soil Colour – A standardised set of colours defined within the Munsell Soil Color Chart (*Munsell color Company Inc. Baltimore, Maryland 21218, USA*).

Soil organic matter – The organic fraction of soil that includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesised by the soil population. Different methods are used for testing for soil organic matter and these can give rise to different results, so care should be taken to understand the impact of the method used on the results obtained. This is a complex subject, which is well summarised by NRM in their Technical Advice Sheet 38: "Soil Organic Matter/Carbon – Which Method to Use?".

Soil texture – The percentage of sand, silt and clay in a soil. The full range of possible soil texture classes, and the relative percentages of sand, silt and clay within in them (as currently defined in the UK) are shown in Figure 1. Abbreviations for the various textures are as follows: sand (S); loamy sand (LS); sandy loam (SL); sandy clay loam (SCL); sandy clay (SC); clay (C); clay loam (CL); sandy clay loam (SCL); silt loam (ZL); silty clay loam (ZCL); sandy silt loam (SZL)

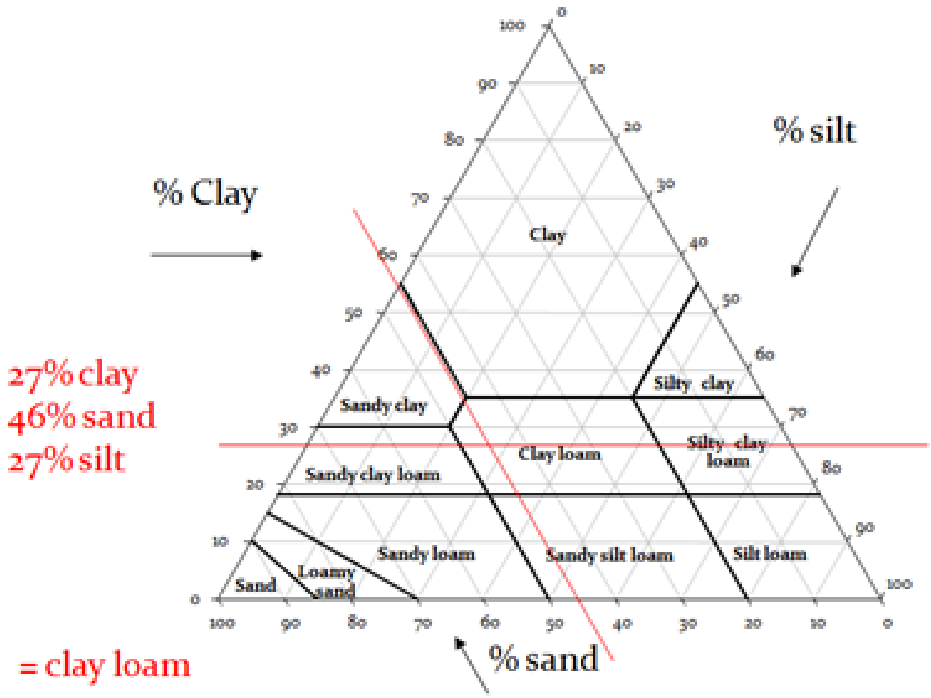


Figure 1. The soil texture triangle used in the UK

Soil structure – The way in which the sand, silt and clay (and in some cases larger mineral particles) combine with humus to form aggregates, leaving pores and channels for air, water, plant roots and microorganisms to move through. Good soil structure is vital for the healthy growth of plants. It can be assessed in various ways, including the VESS system used in this project (see VESS).

SubVESS - A system for assessing the structure of subsoil (see VESS).

VESS – Short for Visual Assessment of Soil Structure, this is a method developed by Dr Bruce Ball of SRUC to assess soil structure quickly and effectively in the field. The method description is available online (https://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure).

There are five topsoil structural classes from 1 and 2 (good) to 4 and 5 (poor). A method to assess the structure of the lower soil layers (known as SubVESS) is also available on the site.

Weed species – a weed can be defined as "a plant growing in the wrong place". In the case of the vegetation assessments conducted in this project, a weed could be defined as a species that is present in an area but was not deliberately sown. However, some weed species, such as native legumes (including birdsfoot trefoil and black medick) cause few problems in a grazed sward, and many farmers believe them to be beneficial for grazing animals. A diverse sward which contains a mixture of species is also likely to be more beneficial for wildlife including insects, spiders and the larger organisms which depend on them, than swards which contain one or very few species. Some weed species are problematic though. For example rushes, creeping thistles, docks and nettles have little food value for grazing animals and if left uncontrolled, can quickly spread in pasture, reducing the grazing value of affected fields.

10 Appendices

Appendix 1. Notes from initial site surveys

Appendix 1 – Notes from initial site surveys

Site 1

Site walkover July 4 2017: Identification of detailed study points

During a second walkover it became much clearer as to which areas have received treatment. We proposed the inclusion of an "un treated" area.

Area 1

Dense mixed vegetation with clearly identified boundary's between untreated and untreated areas.

Plate 1: Area 1, showing evidence of soil formation and weed species.

Plate 2: Vegetation in Area 1.

Plate 3: Demarcation between treated and untreated (or less treated) parts of Area 1.

Area 2

There was a clear boundary surrounding the treatment area in terms of vegetation and soil surface conditions. Good evidence of soil formation.

Plate 4: Area 2, showing some evidence of soil formation and some evidence of organic matter at 20 cm depth.

Plate 5: Area 2, showing weedy vegetation. There was a clear boundary around the treatment area in terms of vegetation type and soil surface conditions.

Area 3

Dense vegetation with rushes and other weed species. Clearly identifiable boundary was visible between treated and untreated parts of the area. There was evidence of organic matter at 30 cm depth.

Plate 6: Area 3, showing dense vegetation and some indication of organic matter at 30 cm depth.

Plate 7: Area 3, looking from the treated part of the area across to untreated (or less treated) land.

Area 4

Heavy cover of weedy vegetation was obvious across much of the area, with a clear boundary between treated and untreated parts of the area.

Plate 8: Area 4, showing dense weed cover within a clear boundary and signs of organic matter in profile.

Area 5

Of all the areas examined, this is the one with the least certainty as to treatment type, based on vegetation growth. It has clearly been treated but it was not possible to identify a clear treatment boundary.

Plate 9: Area 5, showing clear evidence of treatment but plant density was less than other points.

Plate 10: Area 5, showing strong growth of weed species but plant density is less than other locations.

Area 6

This untreated area was proposed for inclusion. As indicated above there were untreated or "less treated" areas across the site. This area was chosen because it had the clearest indications of having been land-formed but not amended with sludge.

The pictures at this location were blurry (heavy rain and mud on the lens!) and could not be included. This area had low height vegetation cover and similar soils in terms of texture as Areas 3 and 4.

NOTES

Having spent a full day walking the site the treatment areas became very evident and we were confident that we have found five appropriate treated areas and one untreated area.

Bill Crooks
July 2017

Site 2

Site walkover July 3 2017: Identification of details study points

Six areas were proposed for detailed investigation. An initial discussion with the land restoration contractor revealed that two separate techniques of incorporation had been used on the site and that a small area of un-remediated land still exists. Based on the site walkover, we recommended six areas summarised for detailed investigations as follows:

1. Two study study areas where sludges were surface-applied and then disked in using heavy disks.
2. Three study areas where sludge had been incorporated using double digging followed by light surface disking.
3. One study area where no sludge amendment occurred. The area has been land-formed but no sludge or other organic materials have been incorporated.

Two areas restored using surface application following by disking (Areas 1 and 2)

Both areas (Areas 1 and 2) were uniform in terms of drainage (which was good), vegetation type and percentage vegetation cover. The two locations were chosen to represent different parts of the site.

Plate 114: Example of topsoil and vegetation in an area restored using a disking method (Areas 1 and 2).

Three areas representing the double digging restoration method (Areas 3, 4 and 5)

Areas 3, 4 and 5 represented typical restoration outcomes for the site (based on quick vegetation assessments and quick spade digs in the topsoil). The first, which was poorly drained, was covered in a mixture of rushes, pasture grasses and weed grasses. Poor drainage is common in this geographical area, and the presence of poor drainage is not a judgment on the success of the restoration. Overall this represented approximately a third of the area restored using sludge with a double digging methodology.

Plate 122: Areas restored with double and digging, poor drainage (Areas 3, 4 and 5).

The other two areas each represented approximately one third of the total area restored using the double digging methodology. Both were slightly better drained than Area 3 and were covered with a reasonable to good percentage cover of target vegetation (i.e. sown pasture grasses).

Plate 133: Area restored with double digging soil is well-drained , good cover of desirable, sown plant species.

Un-restored land (Area 6)

This was a relatively small, low lying area with reasonable drainage that was not included in the original remediation program. The ground surface was very compact and there was little or no vegetation present on it at the time of the initial site visit.

Plate 114: Un-amended soil in Area 6.

The site was land-formed at the same time as those areas remediated in 2013 – 14. It is proposed that this study site will provide useful baseline data to indicate what the site was like prior to sludge applications.

Bill Crooks
July 2017

Appendix 2. DAFOR scores – how they were assigned

The DAFOR scale records the relative abundance of species found in a quadrat or study area as follows: D = Dominant; A = Abundant, F = Frequent, O = Occasional, R = Rare. Each species present in a study area or quadrat was identified and listed. Once all plants have been identified, a DAFOR letter was assigned to each species depending on its abundance.
The letters were assigned using the following guide:

D for Dominant

In practice this was rarely used. To score D, a species had to be the most common plant by far, in well over three quarters of the square. It was occasionally used in this survey where ground was heavily overgrown by a weed species. It might also happen in recently sown grassland where perennial ryegrass was dominant.

A for Abundant

This letter was only used where a plant species was very common in many parts of the square. In most squares, few species scored as highly as A and in quite a few squares there will be no species that score that highly.

F for Frequent

This was used where a plant species was found in several places in an area square and there was usually more than just a few individuals in each of these places. F was also used where a plant was only present in one part of the square but was very common in that part, with many individuals and covered a substantial area (e.g. between one eight and one quarter of the area of the whole square).

O for Occasional

This was used where a plant species occurred in several places in the square, but where the populations were usually not very big. O was also used for species that were very common in one part of a habitat within the square that occupied just a small area (e.g less than one eighth of the area of the whole square). O was used for many species in most squares.

R for Rare

This was used for any species that occurred as a small number of individuals in a square. This small number of individuals may be located in one place in the square, or scattered over several different locations within the square. In the more floristically diverse squares on poorer ground, R could be the score that most species were assigned.

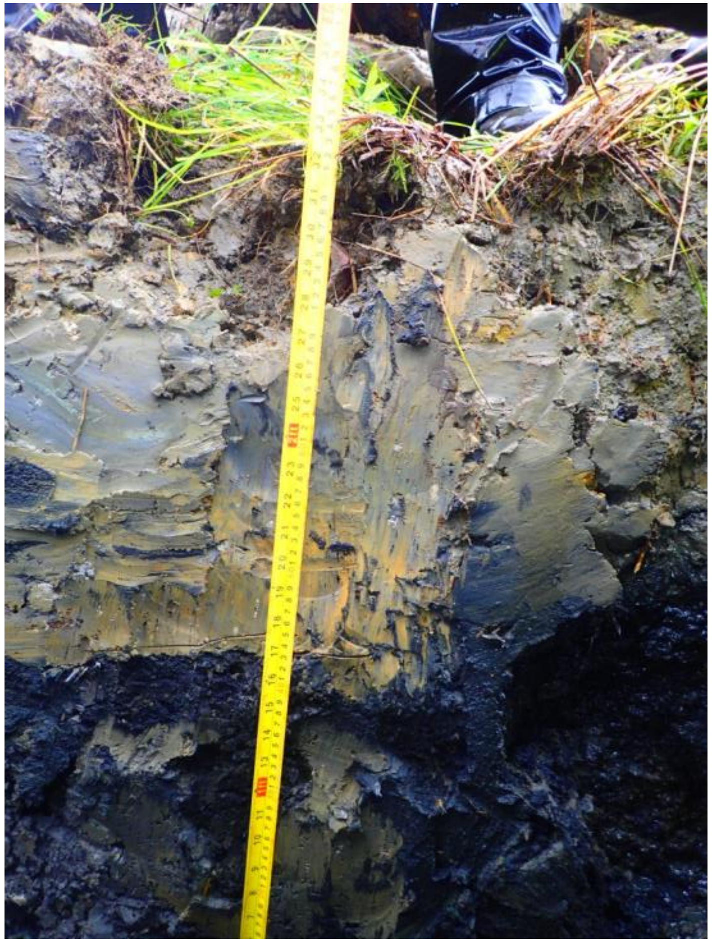
Appendix 3. Photographs of soil pits

Site 1: Area 1

Site1: Area 2

Site 1: Area 2

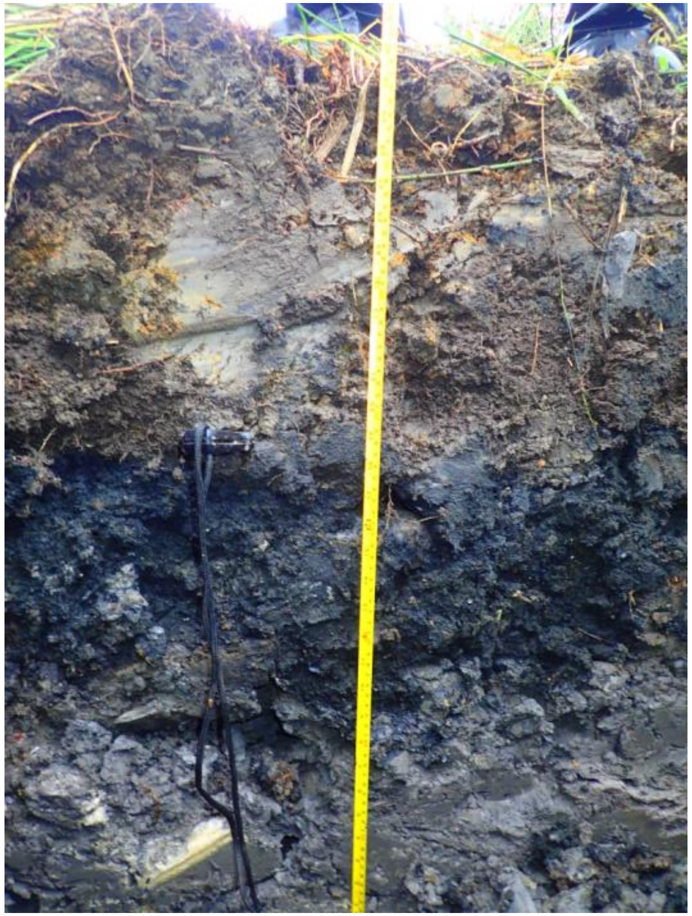
Site1: Area 3



Site 1: Area 3

Site 1: Area 4

Site 1: Area 4



Site 1: Area 5

Site 1: Area 5

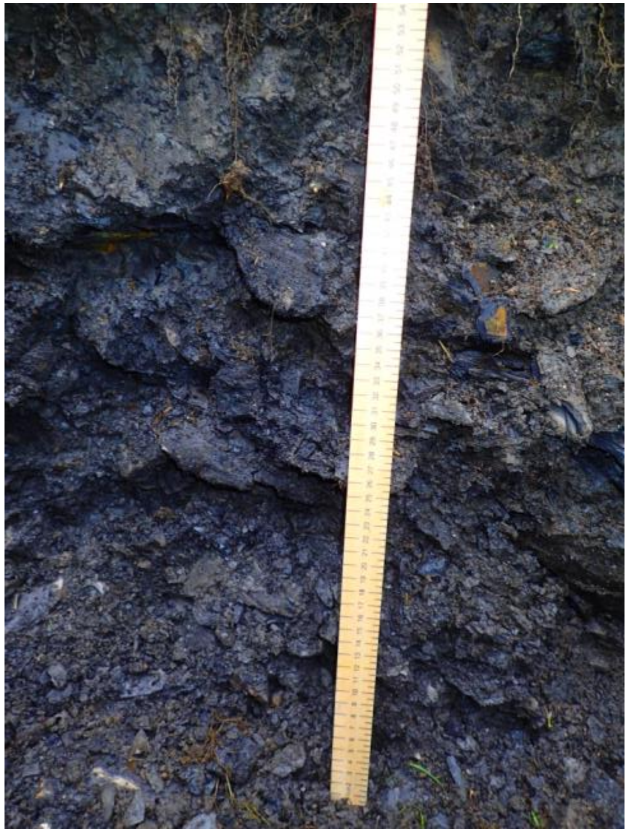
Site 1: Area 5

Site 1: Area 6 Control

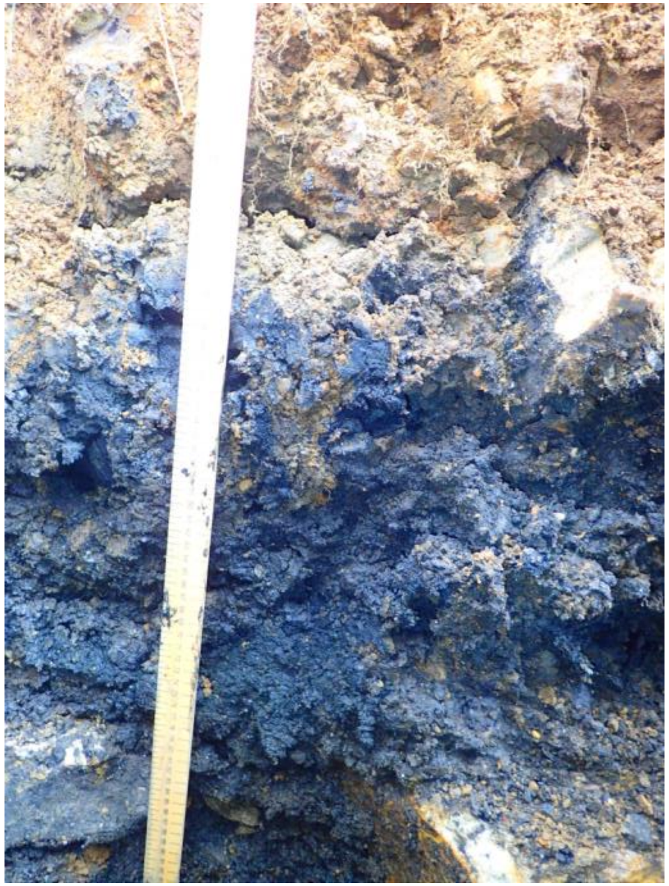
Site 2: Area 1

Site 2: Area 1

Site 2: Area 2

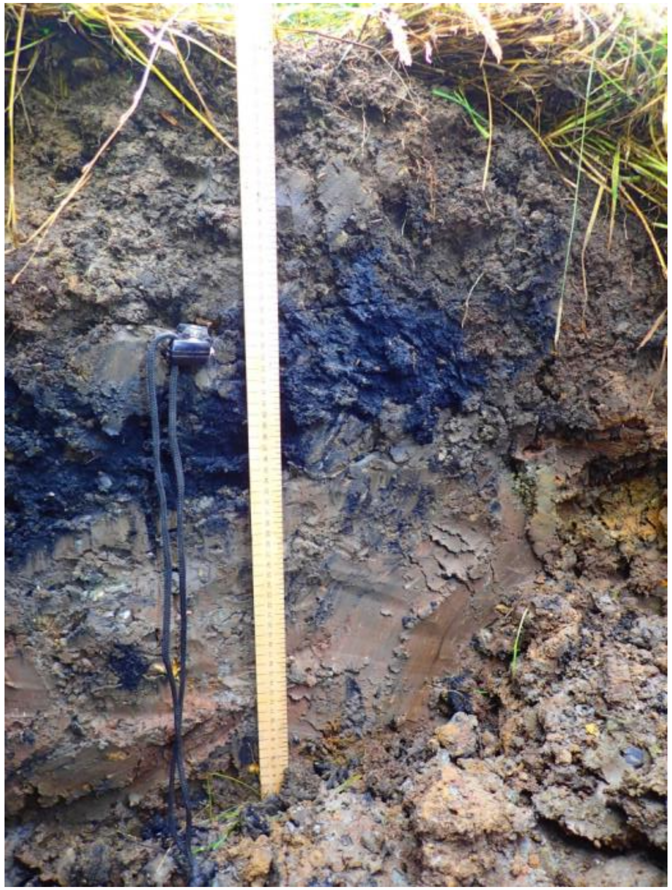


Site 2: Area 3



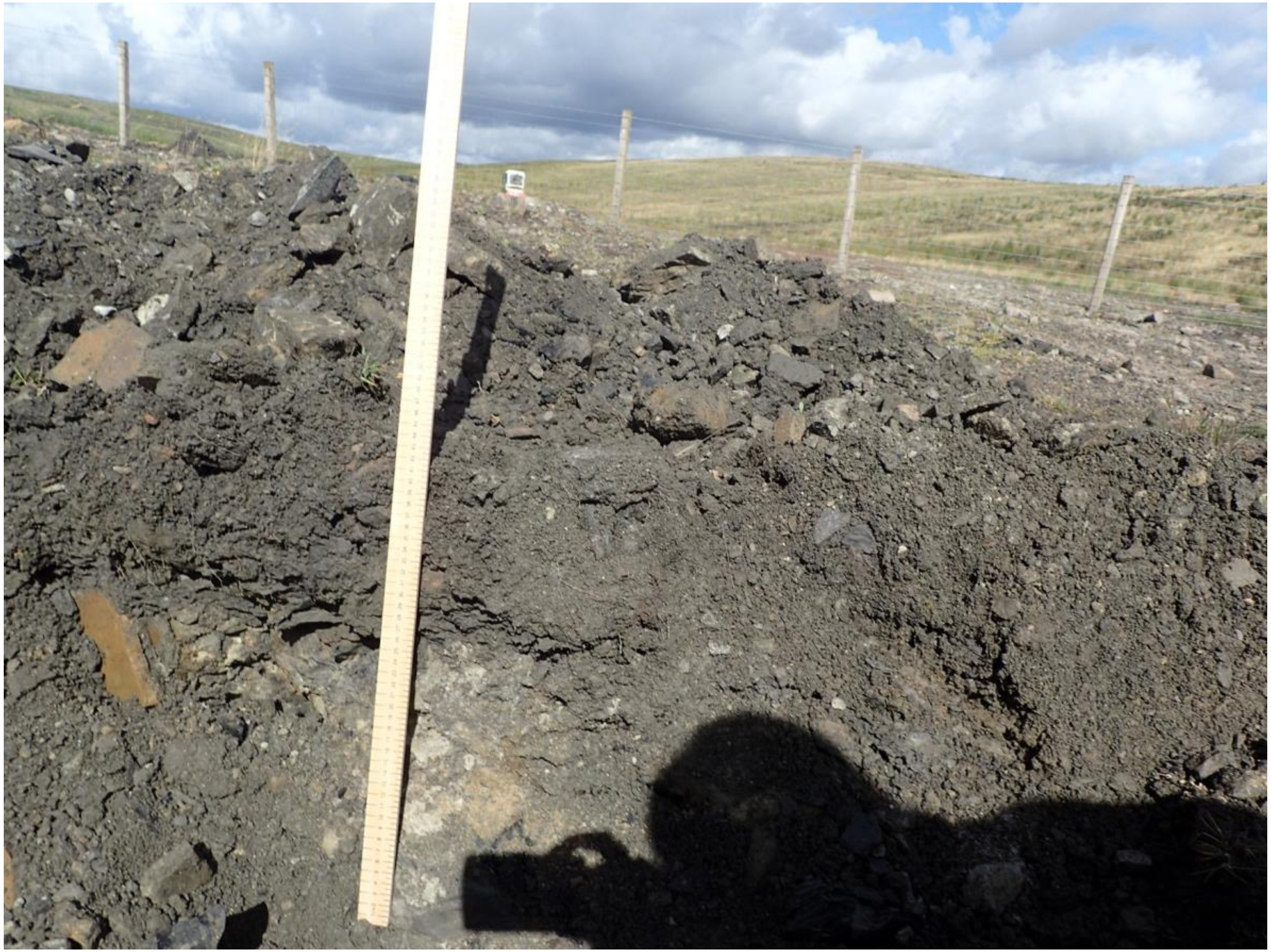
Site 2: Area 4

Site 2: Area 5



Site 2: Area 6

Site 2: Area 6



Site 2: Area 6

Appendix 4. Soil and sludge analysis: full results

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Sewage Sludge: Site 1

Location 1 Layer 3

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64794

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.
The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84929

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result	Amount per fresh tonne	Amount applied at an equivalent total Nitrogen application of 250 kg N/ha	Units
pH 1:6 [Fresh]		7.90			
Oven Dry Matter	%	26.7	267.00	8197	kg DM
Total Nitrogen	% w/w	3.05	8.14	250	kg N
Ammonium Nitrogen	mg/kg	5052	1.35	41.41	kg NH4-N
Nitrate Nitrogen	mg/kg	<10	< 0.01		kg NO3-N
Total Phosphorus (P)	% w/w	1.61	9.84	302.20	kg P2O5
Total Potassium (K)	% w/w	0.115	0.37	11.31	kg K2O
Total Magnesium (Mg)	% w/w	0.733	3.25	99.74	kg MgO
Total Copper (Cu)	mg/kg	222	0.06	1.82	kg Cu
Total Zinc (Zn)	mg/kg	672	0.18	5.51	kg Zn
Equivalent field application rate		——	1.00	30.70	tonnes/ha

The above equivalent field application rate for total nitrogen of 250 kg/ha has been provided purely for guidance purposes only. Organic manures should be used in accordance with the Defra Code of Good Agricultural Practice and where required within the specific regulatory guidance for the spreading of that material to land. To get the most benefit from your organic manures it is recommended that you follow the principles as set out in Defra's Fertiliser Manual (RB209) or as directed by a FACTS qualified adviser.

Released by Joe Cherrie Date 11/10/17

Purchase Order : 20114721

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SEAMUS MURPHY

BC SM
Sewage Sludge: Site 1

Location 1 Layer 3

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64794

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84929

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result
Organic Carbon by DUMAS	%	23.0
Organic Matter [calculation]	%	39.5
Total Carbon	% w/w	24.0
Total Lead (Pb)	mg/kg	175
Total Cadmium (Cd)	mg/kg	1.08
Total Mercury (Hg)	mg/kg	0.846
Total Nickel (Ni)	mg/kg	43.5
Total Chromium (Cr)	mg/kg	124
Organic Matter LOI	% w/w	40.3
Water Soluble Magnesium	mg/kg	63.7
Water Soluble Phosphorus	mg/kg	44.1
Water Soluble Potassium	mg/kg	213

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SEAMUS MURPHY

BC SM
Sewage Sludge: Site 1

Location 2 Layer 3

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64798

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84930

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result	Amount per fresh tonne	Amount applied at an equivalent total Nitrogen application of 250 kg N/ha	Units
pH 1:6 [Fresh]		8.10			
Oven Dry Matter	%	23.7	237.00	5967	kg DM
Total Nitrogen	% w/w	4.19	9.93	250	kg N
Ammonium Nitrogen	mg/kg	5802	1.38	34.62	kg NH4-N
Nitrate Nitrogen	mg/kg	<10	< 0.01		kg NO3-N
Total Phosphorus (P)	% w/w	2.51	13.62	342.95	kg P2O5
Total Potassium (K)	% w/w	0.121	0.34	8.66	kg K2O
Total Magnesium (Mg)	% w/w	0.727	2.86	72.01	kg MgO
Total Copper (Cu)	mg/kg	272	0.06	1.62	kg Cu
Total Zinc (Zn)	mg/kg	666	0.16	3.97	kg Zn
Equivalent field application rate		——	1.00	25.18	tonnes/ha

The above equivalent field application rate for total nitrogen of 250 kg/ha has been provided purely for guidance purposes only. Organic manures should be used in accordance with the Defra Code of Good Agricultural Practice and where required within the specific regulatory guidance for the spreading of that material to land. To get the most benefit from your organic manures it is recommended that you follow the principles as set out in Defra's Fertiliser Manual (RB209) or as directed by a FACTS qualified adviser.

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SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64798

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84930

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result
Organic Carbon by DUMAS	%	29.2
Organic Matter [calculation]	%	50.3
Total Carbon	% w/w	28.6
Total Lead (Pb)	mg/kg	262
Total Cadmium (Cd)	mg/kg	1.63
Total Mercury (Hg)	mg/kg	1.02
Total Nickel (Ni)	mg/kg	24.0
Total Chromium (Cr)	mg/kg	33.6
Organic Matter LOI	% w/w	53.0
Water Soluble Magnesium	mg/kg	80.2
Water Soluble Phosphorus	mg/kg	224
Water Soluble Potassium	mg/kg	247

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SEAMUS MURPHY

BC SM
Sewage Sludge: Site 1

Location 3 Layer 3

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64801

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84931

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result	Amount per fresh tonne	Amount applied at an equivalent total Nitrogen application of 250 kg N/ha	Units
pH 1:6 [Fresh]		7.46			
Oven Dry Matter	%	20.5	205.00	4529	kg DM
Total Nitrogen	% w/w	5.52	11.32	250	kg N
Ammonium Nitrogen	mg/kg	15571	3.19	70.52	kg NH4-N
Nitrate Nitrogen	mg/kg	<10	< 0.01		kg NO3-N
Total Phosphorus (P)	% w/w	2.03	9.53	210.54	kg P2O5
Total Potassium (K)	% w/w	0.200	0.49	10.87	kg K2O
Total Magnesium (Mg)	% w/w	0.642	2.18	48.27	kg MgO
Total Copper (Cu)	mg/kg	161	0.03	0.73	kg Cu
Total Zinc (Zn)	mg/kg	429	0.09	1.94	kg Zn
Equivalent field application rate		——	1.00	22.09	tonnes/ha

The above equivalent field application rate for total nitrogen of 250 kg/ha has been provided purely for guidance purposes only. Organic manures should be used in accordance with the Defra Code of Good Agricultural Practice and where required within the specific regulatory guidance for the spreading of that material to land. To get the most benefit from your organic manures it is recommended that you follow the principles as set out in Defra's Fertiliser Manual (RB209) or as directed by a FACTS qualified adviser.

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SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64801

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84931

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result
Organic Carbon by DUMAS	%	35.9
Organic Matter [calculation]	%	61.7
Total Carbon	% w/w	36.6
Total Lead (Pb)	mg/kg	106
Total Cadmium (Cd)	mg/kg	0.574
Total Mercury (Hg)	mg/kg	0.792
Total Nickel (Ni)	mg/kg	32.4
Total Chromium (Cr)	mg/kg	22.4
Organic Matter LOI	% w/w	65.4
Water Soluble Magnesium	mg/kg	964
Water Soluble Phosphorus	mg/kg	347
Water Soluble Potassium	mg/kg	960

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SEAMUS MURPHY

BC SM
Sewage Sludge: Site 1

Location 4 Layer 2

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64804

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84932

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result	Amount per fresh tonne	Amount applied at an equivalent total Nitrogen application of 250 kg N/ha	Units
pH 1:6 [Fresh]		8.00			
Oven Dry Matter	%	27.0	270.00	9470	kg DM
Total Nitrogen	% w/w	2.64	7.13	250	kg N
Ammonium Nitrogen	mg/kg	4122	1.11	39.03	kg NH4-N
Nitrate Nitrogen	mg/kg	<10	< 0.01		kg NO3-N
Total Phosphorus (P)	% w/w	1.36	8.41	294.92	kg P2O5
Total Potassium (K)	% w/w	0.135	0.44	15.34	kg K2O
Total Magnesium (Mg)	% w/w	0.638	2.86	100.29	kg MgO
Total Copper (Cu)	mg/kg	269	0.07	2.55	kg Cu
Total Zinc (Zn)	mg/kg	632	0.17	5.98	kg Zn
Equivalent field application rate		——	1.00	35.07	tonnes/ha

The above equivalent field application rate for total nitrogen of 250 kg/ha has been provided purely for guidance purposes only. Organic manures should be used in accordance with the Defra Code of Good Agricultural Practice and where required within the specific regulatory guidance for the spreading of that material to land. To get the most benefit from your organic manures it is recommended that you follow the principles as set out in Defra's Fertiliser Manual (RB209) or as directed by a FACTS qualified adviser.

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BC SM
Sewage Sludge: Site 1

Location 4 Layer 2

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64804

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84932

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result
Organic Carbon by DUMAS	%	25.5
Organic Matter [calculation]	%	43.9
Total Carbon	% w/w	25.2
Total Lead (Pb)	mg/kg	155
Total Cadmium (Cd)	mg/kg	0.846
Total Mercury (Hg)	mg/kg	0.678
Total Nickel (Ni)	mg/kg	30.4
Total Chromium (Cr)	mg/kg	35.0
Organic Matter LOI	% w/w	48.1
Water Soluble Magnesium	mg/kg	38.1
Water Soluble Phosphorus	mg/kg	46.6
Water Soluble Potassium	mg/kg	176

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BC SM
Sewage Sludge: Site 1

Location 5 Layer 3

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64807

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84933

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result	Amount per fresh tonne	Amount applied at an equivalent total Nitrogen application of 250 kg N/ha	Units
pH 1:6 [Fresh]		8.26			
Oven Dry Matter	%	29.1	291.00	6494	kg DM
Total Nitrogen	% w/w	3.85	11.20	250	kg N
Ammonium Nitrogen	mg/kg	5007	1.46	32.51	kg NH4-N
Nitrate Nitrogen	mg/kg	<10	< 0.01		kg NO3-N
Total Phosphorus (P)	% w/w	2.05	13.66	304.84	kg P2O5
Total Potassium (K)	% w/w	0.132	0.46	10.29	kg K2O
Total Magnesium (Mg)	% w/w	0.915	4.42	98.63	kg MgO
Total Copper (Cu)	mg/kg	166	0.05	1.08	kg Cu
Total Zinc (Zn)	mg/kg	518	0.15	3.36	kg Zn
Equivalent field application rate		——	1.00	22.31	tonnes/ha

The above equivalent field application rate for total nitrogen of 250 kg/ha has been provided purely for guidance purposes only. Organic manures should be used in accordance with the Defra Code of Good Agricultural Practice and where required within the specific regulatory guidance for the spreading of that material to land. To get the most benefit from your organic manures it is recommended that you follow the principles as set out in Defra's Fertiliser Manual (RB209) or as directed by a FACTS qualified adviser.

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BC SM
Sewage Sludge: Site 1

Location 5 Layer 3

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64807

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84933

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result
Organic Carbon by DUMAS	%	23.4
Organic Matter [calculation]	%	40.3
Total Carbon	% w/w	26.4
Total Lead (Pb)	mg/kg	207
Total Cadmium (Cd)	mg/kg	0.612
Total Mercury (Hg)	mg/kg	0.868
Total Nickel (Ni)	mg/kg	27.8
Total Chromium (Cr)	mg/kg	30.9
Organic Matter LOI	% w/w	51.2
Water Soluble Magnesium	mg/kg	121
Water Soluble Phosphorus	mg/kg	202
Water Soluble Potassium	mg/kg	241

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SEAMUS MURPHY

BC SM
Sewage Sludge: Site 2

Location 3 Layer 3

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64785

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84926

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result	Amount per fresh tonne	Amount applied at an equivalent total Nitrogen application of 250 kg N/ha	Units
pH 1:6 [Fresh]		7.26			
Oven Dry Matter	%	61.3	613.00	32051	kg DM
Total Nitrogen	% w/w	0.78	4.78	250	kg N
Ammonium Nitrogen	mg/kg	269	0.16	8.62	kg NH4-N
Nitrate Nitrogen	mg/kg	<10	< 0.01		kg NO3-N
Total Phosphorus (P)	% w/w	0.336	4.72	246.62	kg P2O5
Total Potassium (K)	% w/w	0.156	1.15	60.00	kg K2O
Total Magnesium (Mg)	% w/w	0.452	4.60	240.49	kg MgO
Total Copper (Cu)	mg/kg	73.4	0.04	2.35	kg Cu
Total Zinc (Zn)	mg/kg	238	0.15	7.63	kg Zn
Equivalent field application rate		——	1.00	52.29	tonnes/ha

The above equivalent field application rate for total nitrogen of 250 kg/ha has been provided purely for guidance purposes only. Organic manures should be used in accordance with the Defra Code of Good Agricultural Practice and where required within the specific regulatory guidance for the spreading of that material to land. To get the most benefit from your organic manures it is recommended that you follow the principles as set out in Defra's Fertiliser Manual (RB209) or as directed by a FACTS qualified adviser.

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D713

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SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64785

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84926

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result
Organic Carbon by DUMAS	%	21.2
Organic Matter [calculation]	%	36.5
Total Carbon	% w/w	17.3
Total Lead (Pb)	mg/kg	47.6
Total Cadmium (Cd)	mg/kg	0.774
Total Mercury (Hg)	mg/kg	<0.2
Total Nickel (Ni)	mg/kg	38.1
Total Chromium (Cr)	mg/kg	29.5
Organic Matter LOI	% w/w	24.3
Water Soluble Magnesium	mg/kg	99.5
Water Soluble Phosphorus	mg/kg	8.73
Water Soluble Potassium	mg/kg	64.2

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SEAMUS MURPHY

BC SM
Sewage Sludge: Site 2

Location 4 Layer 3

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64787

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84927

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result	Amount per fresh tonne	Amount applied at an equivalent total Nitrogen application of 250 kg N/ha	Units
pH 1:6 [Fresh]		7.60			
Oven Dry Matter	%	26.1	261.00	5708	kg DM
Total Nitrogen	% w/w	4.38	11.43	250	kg N
Ammonium Nitrogen	mg/kg	9226	2.41	52.66	kg NH4-N
Nitrate Nitrogen	mg/kg	<10	< 0.01		kg NO3-N
Total Phosphorus (P)	% w/w	1.18	7.05	154.24	kg P2O5
Total Potassium (K)	% w/w	0.174	0.54	11.92	kg K2O
Total Magnesium (Mg)	% w/w	0.566	2.45	53.63	kg MgO
Total Copper (Cu)	mg/kg	188	0.05	1.07	kg Cu
Total Zinc (Zn)	mg/kg	458	0.12	2.61	kg Zn
Equivalent field application rate		——	1.00	21.87	tonnes/ha

The above equivalent field application rate for total nitrogen of 250 kg/ha has been provided purely for guidance purposes only. Organic manures should be used in accordance with the Defra Code of Good Agricultural Practice and where required within the specific regulatory guidance for the spreading of that material to land. To get the most benefit from your organic manures it is recommended that you follow the principles as set out in Defra's Fertiliser Manual (RB209) or as directed by a FACTS qualified adviser.

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SEAMUS MURPHY

BC SM
Sewage Sludge: Site 2

Location 4 Layer 3

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64787

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84927

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result
Organic Carbon by DUMAS	%	37.9
Organic Matter [calculation]	%	65.2
Total Carbon	% w/w	40.4
Total Lead (Pb)	mg/kg	96.1
Total Cadmium (Cd)	mg/kg	1.87
Total Mercury (Hg)	mg/kg	0.525
Total Nickel (Ni)	mg/kg	19.1
Total Chromium (Cr)	mg/kg	24.5
Organic Matter LOI	% w/w	72.8
Water Soluble Magnesium	mg/kg	138
Water Soluble Phosphorus	mg/kg	96.6
Water Soluble Potassium	mg/kg	892

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Sewage Sludge: Site 2

Location 5 Layer 2

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64790

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84928

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result	Amount per fresh tonne	Amount applied at an equivalent total Nitrogen application of 250 kg N/ha	Units
pH 1:6 [Fresh]		8.41			
Oven Dry Matter	%	36.5	365.00	9434	kg DM
Total Nitrogen	% w/w	2.65	9.67	250	kg N
Ammonium Nitrogen	mg/kg	4636	1.69	43.74	kg NH4-N
Nitrate Nitrogen	mg/kg	<10	< 0.01		kg NO3-N
Total Phosphorus (P)	% w/w	1.30	10.87	280.85	kg P2O5
Total Potassium (K)	% w/w	0.110	0.48	12.45	kg K2O
Total Magnesium (Mg)	% w/w	0.591	3.58	92.55	kg MgO
Total Copper (Cu)	mg/kg	120	0.04	1.13	kg Cu
Total Zinc (Zn)	mg/kg	357	0.13	3.37	kg Zn
Equivalent field application rate		——	1.00	25.85	tonnes/ha

The above equivalent field application rate for total nitrogen of 250 kg/ha has been provided purely for guidance purposes only. Organic manures should be used in accordance with the Defra Code of Good Agricultural Practice and where required within the specific regulatory guidance for the spreading of that material to land. To get the most benefit from your organic manures it is recommended that you follow the principles as set out in Defra's Fertiliser Manual (RB209) or as directed by a FACTS qualified adviser.

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SEAMUS MURPHY

BC SM
Sewage Sludge: Site 2

Location 5 Layer 2

SLUDGE ANALYSIS RESULTS (Metric Units)

Sample Reference : 64790

Sample Matrix : SLUDGE

The sample submitted was of adequate size to complete all analysis requested.

The sample will be kept as the dry ground sample for at least 1 month.

Laboratory References	
Report Number	76351
Sample Number	84928

Date Received	03-OCT-2017
Date Reported	11-OCT-2017

ANALYTICAL RESULTS

Determinand on a DM basis unless otherwise indicated	Units	Result
Organic Carbon by DUMAS	%	15.5
Organic Matter [calculation]	%	26.7
Total Carbon	% w/w	17.2
Total Lead (Pb)	mg/kg	113
Total Cadmium (Cd)	mg/kg	0.427
Total Mercury (Hg)	mg/kg	0.400
Total Nickel (Ni)	mg/kg	25.8
Total Chromium (Cr)	mg/kg	31.6
Organic Matter LOI	% w/w	32.8
Water Soluble Magnesium	mg/kg	37.6
Water Soluble Phosphorus	mg/kg	160
Water Soluble Potassium	mg/kg	176

Released by Joe Cherrie .... Date 11/10/17 ....

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ANALYTICAL REPORT

Report Number	**76354-17**	**D713**	**SEAMUS MURPHY**	**Client**
Date Received	**03-OCT-2017**		**SAC ENVIRONMENTAL**	
Date Reported	**11-OCT-2017**		**JOHN F NIVEN BUILDING**	
Project	**BC SM**		**SAC**	
Reference	**SEAMUS MURPHY**		**AUCHINCRUIVE**	
Order Number	**20114721**		**KA6 5HW**	

Laboratory Reference		**SOIL359269**	**SOIL359270**	**SOIL359271**	**SOIL359272**	**SOIL359273**	**SOIL359274**	**SOIL359275**	**SOIL359276**	**SOIL359277**	**SOIL359278**
Sample Reference		**Site 1 Area 1 Layer 1**	**Site 1 Area 1 Layer 2**	**Site 1 Area 1 Layer 4**	**Site 1 Area 2 Layer 1**	**Site 1 Area 2 Layer 2**	**Site 1 Area 3 Layer 1**	**Site 1 Area 3 Layer 2**	**Site 1 Area 4 Layer 1**	**Site 1 Area 4 Layer 3**	**Site 1 Area 5 Layer 1**
Determinand	**Unit**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**
pH water [1:2.5]		7.9	7.1	7.0	5.5	6.7	5.3	7.6	5.5	7.4	8.0
Available Phosphorus (Index)	mg/l	<2.5 (0)	5.2 (0)	4.8 (0)	8.8 (0)	3.4 (0)	5.0 (0)	<2.5 (0)	30.4 (3)	4.4 (0)	<2.5 (0)
Available Potassium (Index)	mg/l	116 (1)	152 (2-)	114 (1)	114 (1)	150 (2-)	87.4 (1)	220 (2+)	150 (2-)	137 (2-)	112 (1)
Available Magnesium (Index)	mg/l	333 (5)	467 (6)	304 (5)	197 (4)	342 (5)	244 (4)	416 (6)	266 (5)	308 (5)	330 (5)
Organic Matter LOI	% w/w	6.5	6.0	5.8	8.3	3.3	4.8	5.6	6.9	4.4	6.1
Total Nitrogen	% w/w	0.170	0.240	0.180	0.250	0.120	0.170	0.170	0.190	0.170	0.200
Total Copper	mg/kg	38.4	37.4	34.8	19.7	34.2	30.1	36.9	36.9	27.2	39.3
Total Zinc	mg/kg	76.7	122	72.8	48.4	80.2	65.1	90.1	95.3	80.3	80.9
Total Lead	mg/kg	24.4	23.3	22.2	41.4	19.7	27.1	25.4	24.8	18.5	21.0
Total Cadmium	mg/kg	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total Nickel	mg/kg	44.3	44.6	36.2	17.9	39.4	35.9	46.7	41.3	36.6	41.8
Total Chromium	mg/kg	39.5	36.0	37.6	37.6	37.3	40.3	39.6	43.7	33.5	36.0
Total Mercury	mg/kg	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Total Phosphorus	mg/kg	417	513	437	387	184	251	472	892	465	499
pH 0.01M CaCl2		7.2	7.1	6.4	4.4	6.3	4.8	7.1	4.6	7.2	7.3
Total Carbon	% w/w	4.80	4.46	3.46	4.36	1.96	2.32	4.81	3.88	3.17	4.27
Carbon:Nitrogen Ratio	:1	28.2	18.6	19.2	17.4	16.3	13.6	28.3	20.4	18.6	21.4
Mod Morgans Phosphorus	mg/l	1.4	1.5	1.5	1.8	1.5	1.4	1.4	3.0	1.4	1.4
Mod Morgans Potassium	mg/l	131	164	129	133	169	91	235	173	146	115
Mod Morgans Magnesium	mg/l	610	637	433	243	516	294	545	355	444	586
Organic Carbon by DUMAS	%	4.9	3.6	2.8	4.1	1.7	2.2	5.1	3.8	2.6	4.1
Organic Matter [calculation]	%	9.4	6.9	5.4	7.9	3.3	4.3	9.6	7.3	5.0	7.8

ANALYTICAL REPORT

Report Number	**76355-17**	**D713**	**SEAMUS MURPHY**	**Client**
Date Received	**03-OCT-2017**		**SAC ENVIRONMENTAL**	
Date Reported	**11-OCT-2017**		**JOHN F NIVEN BUILDING**	
Project	**BC SM**		**SAC**	
Reference	**SEAMUS MURPHY**		**AUCHINCRUIVE**	
Order Number	**20114721**		**KA6 5HW**	

Laboratory Reference		**SOIL359279**	**SOIL359280**	**SOIL359281**							
Sample Reference		**Site 1 Area 5 Layer 2**	**Site 1 Area 6 Layer 1**	**Site 1 Area 6 Layer 2**							
Determinand	**Unit**	**SOIL**	**SOIL**	**SOIL**							
pH water [1:2.5]		7.9	7.9	5.9							
Available Phosphorus (Index)	mg/l	3.8 (0)	2.8 (0)	7.0 (0)							
Available Potassium (Index)	mg/l	110 (1)	59.6 (0)	78.0 (1)							
Available Magnesium (Index)	mg/l	417 (6)	300 (5)	287 (5)							
Organic Matter LOI	% w/w	5.8	3.5	3.1							
Total Nitrogen	% w/w	0.180	0.130	0.100							
Total Copper	mg/kg	37.5	20.8	23.8							
Total Zinc	mg/kg	75.6	45.8	76.0							
Total Lead	mg/kg	19.8	17.1	18.0							
Total Cadmium	mg/kg	<0.1	<0.1	<0.1							
Total Nickel	mg/kg	41.7	26.2	27.0							
Total Chromium	mg/kg	37.4	32.2	45.4							
Total Mercury	mg/kg	<0.2	<0.2	<0.2							
Total Phosphorus	mg/kg	535	232	326							
pH 0.01M CaCl2		7.2	6.9	5.5							
Total Carbon	% w/w	3.37	2.28	1.32							
Carbon:Nitrogen Ratio	:1	18.7	17.5	13.2							
Mod Morgans Phosphorus	mg/l	1.5	1.4	1.5							
Mod Morgans Potassium	mg/l	91	55	69							
Mod Morgans Magnesium	mg/l	599	398	303							
Organic Carbon by DUMAS	%	3.3	1.7	1.5							
Organic Matter [calculation]	%	6.4	3.4	3.1							

ANALYTICAL REPORT

Report Number	**76353-17**	**D713**	**SEAMUS MURPHY**	**Client**
Date Received	**03-OCT-2017**		**SAC ENVIRONMENTAL**	
Date Reported	**11-OCT-2017**		**JOHN F NIVEN BUILDING**	
Project	**BC SM**		**SAC**	
Reference	**SEAMUS MURPHY**		**AUCHINCRUIVE**	
Order Number	**20114721**		**KA6 5HW**	

Laboratory Reference		**SOIL359259**	**SOIL359260**	**SOIL359261**	**SOIL359262**	**SOIL359263**	**SOIL359264**	**SOIL359265**	**SOIL359266**	**SOIL359267**	**SOIL359268**
Sample Reference		**Site 2 Area 1 Layer 1**	**Site 2 Area 1 Layer 2**	**Site 2 Area 2 Layer 1**	**Site 2 Area 2 Layer 2**	**Site 2 Area 3 Layer 1**	**Site 2 Area 4 Layer 1**	**Site 2 Area 4 Layer 2**	**Site 2 Area 5 Layer 1**	**Site 2 Area 5 Layer 3**	**Site 2 Area 6 Layer 1**
Determinand	**Unit**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**	**SOIL**
pH water [1:2.5]		7.2	7.8	6.3	7.6	4.7	5.4	6.6	5.2	7.0	7.9
Available Phosphorus (Index)	mg/l	16.8 (2)	9.6 (1)	23.6 (2)	6.0 (0)	4.8 (0)	5.4 (0)	17.0 (2)	56.0 (4)	6.2 (0)	2.8 (0)
Available Potassium (Index)	mg/l	96.5 (1)	113 (1)	64.8 (1)	134 (2-)	48.4 (0)	70.7 (1)	137 (2-)	35.5 (0)	82.2 (1)	70.5 (1)
Available Magnesium (Index)	mg/l	168 (3)	278 (5)	98.5 (2)	228 (4)	190 (4)	300 (5)	228 (4)	168 (3)	264 (5)	282 (5)
Organic Matter LOI	% w/w	5.2	3.4	9.3	6.0	3.5	8.8	9.6	5.6	1.8	3.2
Total Nitrogen	% w/w	0.140	0.080	0.220	0.110	0.080	0.190	0.310	0.180	0.040	0.070
Total Copper	mg/kg	39.6	43.3	45.8	43.0	22.6	26.3	30.8	28.1	22.2	25.3
Total Zinc	mg/kg	100	175	111	97.4	53.2	82.7	108	241	46.4	72.0
Total Lead	mg/kg	19.4	19.4	28.3	25.0	16.0	32.9	38.6	30.6	14.6	21.8
Total Cadmium	mg/kg	<0.1	0.37	<0.1	<0.1	<0.1	<0.1	<0.1	0.61	<0.1	<0.1
Total Nickel	mg/kg	42.9	48.2	40.1	46.8	36.1	34.1	36.5	29.5	31.6	37.5
Total Chromium	mg/kg	45.5	51.2	52.9	44.5	59.1	39.6	37.6	46.5	40.1	45.8
Total Mercury	mg/kg	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Total Phosphorus	mg/kg	734	533	1221	793	384	312	602	1170	329	400
pH 0.01M CaCl2		7.0	7.2	6.0	7.4	4.3	4.7	6.4	4.9	6.7	7.3
Total Carbon	% w/w	3.28	2.15	5.03	3.86	1.62	6.44	7.06	3.37	0.77	2.29
Carbon:Nitrogen Ratio	:1	23.4	26.9	22.9	35.1	20.3	33.9	22.8	18.7	19.3	32.7
Mod Morgans Phosphorus	mg/l	5.3	2.8	3.7	1.9	1.5	1.6	4.9	9.8	2.0	1.4
Mod Morgans Potassium	mg/l	90	127	70	150	48	74	151	42	96	76
Mod Morgans Magnesium	mg/l	231	449	124	327	224	390	314	231	370	405
Organic Carbon by DUMAS	%	3.3	2.0	5.3	3.2	1.2	6.3	8.0	3.3	0.6	1.9
Organic Matter [calculation]	%	6.3	3.4	10.0	6.1	2.4	11.8	15.0	5.8	1.3	3.7

Appendices 5a and 5b. Full vegetation analysis (Site 1 and Site 2)

Appendix 5a. Full vegetation analysis (Site 1)

Methodology

In early July 2017, the six study areas at each site were walked by crossing from side to side in a zig zag pattern in order to gain an accurate record of the species present and their height, density and health. All species present in each study site were listed.

In addition to the above, ten detailed 1 m quadrat assessments were made in each of the six study areas. These were chosen to ensure that all broad combinations of plant species typical to the study areas were represented. The following were recorded in all quadrats:

- Plant species present;
- Abundance of plant species present in each quadrat (DAFOR scores were allocated to each species present in each quadrat. This means that each plant species was considered to be: dominant, abundant, frequent, occasional or rare within the quadrat [Appendix 2]);
- Overall percentage ground cover by higher plants;
- Mean and maximum height of the herbage;
- Health and condition of the plants present.

A score for "Ecological value" was assigned to the vegetation present in each of the six areas on each site. The five scores ranged from "very poor" to "very good" and were defined as follows:

- very (v) poor = very few species and/or a lot of bare soil;
- poor = relatively few species, and/or one or more aggressive species frequent or abundant (see DAFOR, Appendix 2) and/or some bare patches;
- moderate = most soil covered, moderate number of species but one or more aggressive species frequent or abundant;
- good = complete/almost complete soil cover, a reasonable range of flowering species from different families incl. grasses and non-grasses;
- very (v.) good: complete soil cover with a good range of flowering species from different families incl. grasses and non-grasses.

The scores were based on a combined assessment of the:

- total number of species;
- degree to which a very few species in the area were dominant or abundant (rather than there being a broad mix of species, all of which were similarly common in the area);
- percentage ground cover.

The scores were intended to reflect the value of the sward for wild animals and plants, which is likely to depend not only on species richness, but also on the other two factors noted above.

Site 1, Area 1 (50 ha)

Vegetation cover was almost complete and generally very dense. Species present in the entire area are shown in Table 1, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail. Although the authors have heard unofficially (by "word of mouth") that the area was sown, no written records exist of the species used, the rate at which the seed mixture was applied or the application method. It is unlikely that any of the species most commonly found in this area were sown, with the most frequent species being creeping thistle, tufted hair grass, Yorkshire fog and common sorrel.

Table 1. Species present in Site 1, Area 1		***DAFOR score for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Agrostis capillaris[2]	Common Bent	O						F	F			
Angelica sylvestris	Wild Angelica	O										
Anthoxanthum odoratum[2]	Sweet Vernal Grass	R						O				
Anthriscus sylvestris	Cow parsley	R										
Bellis perennis	Daisy	R	R									
Cardamine hirsuta	Hairy Bitter-cress	R										
Carex viridula ssp. viridula	Small-fruited Yellow Sedge	R										
Centaurea nigra	Common Knapweed	R			F							
Chamerion angustifolium	Rosebay Willowherb	O							F		A	F
Cirsium arvense	Creeping Thistle	O		R		R	O	R		O	A	O
Cirsium palustre	Marsh Thistle	F	F	R	F							
Cirsium vulgare	Spear Thistle	R										
Cynosurus cristatus[2]	Crested Dogstail	R										
Dactylis glomerata[2]	Cocksfoot	R										
Dacylorrhiza spp.	Orchid (not sure of species)	R										
Deschampsia caespitosa	Tufted Hair Grass	F	F	F		A				O		
Dryopteris filix-mas	Male Fern	R	R	F								
Epilobium montanum	Broad leaved Willowherb	R								O		
Epilobium palustre	Marsh Willowherb	R										
Equisetum arvense	Horsetail	R	R	R								R
Festuca ovina[2]	Sheep's Fescue	R							F			
Festuca rubra[2]	Red Fescue	R						F	F			
Holcus lanatus	Yorkshire Fog	F					D	A	F			
Holcus mollis	Creeping Soft Grass	A	F		A				O	F	A	
Juncus effusus	Soft Rush	A	A	A		A	O			A	A	F
Lathyrus pratensis	Meadow Vetchling	R		R	O							
Lotus pedunculatus	Greater Birdsfoot Trefoil	R								O		
Phleum pratense[2]	Timothy	O				F		F				A
Plantago lanceolata	Ribwort Plantain	O	A		F			O				
Poa annua	Annual Meadow Grass	R							R			
Ranunculus repens	Creeping Buttercup	O						F				
Rhinanthus minor	Yellow rattle	R	R									
Rosa canina	Dog rose	R										
Rumex acetosa	Common Sorrel	F	R	R	O	F			R	F		
Rumex crispus	Curled Dock	O		R	F					F		A
Rumex obtusifolius	Broad-leaved Dock	R	R	R								
Trifolium pratense[2]	Red Clover	R										
Urtica dioica	Perennial nettle	R										
Vicia cracca	Tufted vetch	R										
[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare. [2]Species may have been sown or could have occurred naturally.												

There were almost no bare patches of soil, with vegetation cover being almost complete other than on a very few small (a few square centimetres here and there) heavily compacted patches. The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Table 2. Although some of the species present had value for wildlife such as insects, spiders and the larger organisms which depend on them, the most abundant species were aggressive and of relatively low ecological value.

Table 2. Percentage ground cover (% GC), vegetation height and plant health in Area 1 in general and in the ten quadrats studied in detail in Area 1.				
		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	100	~65	~100	Plants were generally in robust health. Almost all were of a normal green colour, indicating that the plants had sufficient nutrients.
1	100	60	90	As above
2	100	70	130	As above
3	100	60	90	As above
4	100	70	125	As above
5	100	45	70	As above
6	100	45	80	As above
7	100	40	75	As above
8	100	80	100	As above
9	100	70	95	As above
10	100	60	125	As above

Most plants, including the desirable grass species were of good health and had a size and colour consistent with their textbook descriptions. There was no evidence of nutrient deficiencies in the vegetation.

Site 1, Area 2 (50 ha)

Vegetation cover was variable, often very tall and dense, but generally species-poor. There were patches of species-rich flora, which seemed more common on the more compact parts of the site. Species present in the entire area are shown in Table 3, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail. Although the authors have heard unofficially (by “word of mouth”) that the area was sown, no written records exist of the species used, the rate at which the seed mixture was applied or the application method. It is unlikely that any of the species most commonly found in this area were sown, with the most frequent species being rosebay willowherb, broad-leaved willowherb, tufted hair grass, Yorkshire fog, soft rush and greater birdsfoot trefoil. Some of these plants have useful ecological value, but there were relatively few of the more useful species (such as birdsfoot trefoil and rosebay willowherb).

The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Table 4. Most plants were of good health and had a size and colour consistent with their textbook descriptions.

Table 3. Species present in Site 1, Area 2		***DAFOR score for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Achillea ptarmica	Sneezewort	R			O							
Alnus glutinosa	Common Alder	R										
Anthoxanthum odoratum[2]	Sweet Vernal Grass	R	O									
Anthriscus sylvestris	Cow parsley	R					R					
Bellis perennis	Daisy	R	O					F				
Carex nigra	Common Sedge	O			A							
Carex viridula ssp. viridula	Small-fruited Yellow Sedge	O						F				
Centaurea nigra	Common Knapweed	O		A								
Cerastium fontanum	Common Mouse-ear	R										
Chamerion angustifolium	Rosebay Willowherb	F							R	F	D	A
Cirsium palustre	Marsh Thistle	O	O			O	R	R	F			
Cirsium vulgare	Spear Thistle	R										
Crataegus monogyna	Common Hawthorn	R										
Cynosurus cristatus	Crested Dogstail	R	F									
Dactylis glomerata[2]	Cocksfoot	R										
Dacylorrhiza spp.	Orchid (not sure of species)	R			R							
Deschampsia caespitosa	Tufted Hair Grass	F		A		A	O	O	F			
Dryopteris filix-mas	Male Fern	R										
Elytrigia repens	*Couch Grass*	O										
Epilobium montanum	*Broad leaved Willowherb*	F		O	R	O					F	O
Epilobium palustre	*Marsh Willowherb*	*R*			R				R			
Equisetum arvense	*Horsetail*	*O*					F	F				
Festuca ovina[2]	*Sheep's Fescue*	*O*					O					
Festuca rubra[2]	*Red Fescue*	*O*					O					
Galium aparine	*Sticky Willie*	*R*										R
Holcus lanatus	*Yorkshire Fog*	*A*	F	O			O		A	D	R	A
Holcus mollis	*Creeping Soft Grass*	*O*	O				F					
Juncus effusus	*Soft Rush*	F		O	F	A		F	O			
Lathyrus pratensis	*Meadow Vetchling*	*O*	O	R		O	F		F			
Listera ovata	*Common Twayblade*	*R*										
Lolium perenne[2]	*Perennial Ryegrass*	*R*										
Lotus corniculatus	Common Birdsfoot Trefoil	O	O			O		O				
Lotus pedunculatus	Greater Birdsfoot Trefoil	F		O	F	A	O	O	O			
Phleum pratense[2]	Timothy	R					O					
Plantago lanceolata	Ribwort Plantain	O	F				F					
Potentilla erecta	Tormentil	R					O					
Prunella vulgaris	Self-heal	R						R				
Ranunculus acris	Meadow Buttercup	R										
Ranunculus repens	Creeping Buttercup	R		R				R				
Rhinanthus minor	Yellow rattle	R										
Rubus idaeus	Wild raspberry	R				F						
Rumex acetosa	Common Sorrel	O		O	O	R	O		R			
Rumex crispus	Curled Dock	R							O			
Sagina procumbens	Pearlwort	R	R									
Salix caprea	Goat Willow	R										
Salix viminalis	Osier willow	R										
Sonchus arvensis	Perennial Sowthistle	R										
Stellaria media	Common Chickweed	R										
Taraxacum agg.	Dandelion	R						F				
Trifolium pratense[2]	Red Clover	O	F									
Trifolium repens[2]	White Clover	O	F									
Urtica dioica	Perennial nettle	R										
Vicia cracca	Tufted vetch	R								F		
Vicia hirsuta	Hairy Tare	R	O									
[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare. [2]Species may have been sown or could have occurred naturally.												

Table 4. Percentage ground cover (% GC), vegetation height and plant health in Area 2 in general and in the ten quadrats studied in detail in Area 2.				
		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	100	~50	~80	Plants were generally in robust health. Most were of a normal green colour in accordance with their textbook descriptions. Some areas were dominated by relatively few species, whereas others (particularly the more compact soils) contained more than seven species.
1	100	30	55	As above
2	100	80	120	As above
3	100	35	70	As above
4	100	45	80	As above
5	100	45	80	As above
6	90-100	25	60	As above
7	100	75	135	As above
8	100	50	65	As above
9	100	90	125	As above
10	100	60	80	As above

Site 1, Area 3 (78 ha)

Vegetation cover was variable and often very tall and dense and there were relatively few species present. There were almost no bare patches and those which were present were only a few square cm in size. Species present in the entire area are shown in Table 5, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail. Although the authors have heard unofficially (by "word of mouth") that the area was sown, no written records exist of the species used, the rate at which the seed mixture was applied or the application method. It is unlikely that any of the species most commonly found in this area were sown, with the most frequent species being creeping thistle, tufted hair grass, creeping soft grass, soft rush and creeping buttercup. Although some of the species present had value for wildlife such as insects, spiders and the larger organisms which depend on them, the most abundant species were aggressive and of relatively low ecological value.

The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Table 6. Most plants were of good health and had a size and colour consistent with their textbook descriptions, although some appeared very dark green, as though they were growing in a soil which contained high concentrations of N. There was no evidence of nutrient deficiency.

Table 5. Species present in Site 1, Area 3		***DAFOR score for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Achillea ptarmica	Sneezewort	R										
Agrostis capillaris[2]	Common Bent	R				F						
Alnus glutinosa	Common Alder	O				F						O
Bellis perennis	Daisy	R										
Betula pubescens	Hairy birch	R										
Cirsium arvense	Creeping Thistle	F						A		F	O	A
Cirsium palustre	Marsh Thistle	O								F		
Cirsium vulgare	Spear Thistle	R										
Cynosurus cristatus[2]	Crested Dogstail	R										
Deschampsia caespitosa	Tufted Hair Grass	F	R	O	O			F	F	O		
Epilobium montanum	Broad leaved Willowherb	R										
Equisetum arvense	Horsetail	O					O		O	O	O	
Holcus lanatus	Yorkshire Fog	O				F						
Holcus mollis	Creeping Soft Grass	F					F	F	F	O	A	A
Juncus effuses	Soft Rush	A	A	A	A	A	D	F	A	F		
Lathyrus pratensis	Meadow Vetchling	R										
Lotus pedunculatus	Greater Birdsfoot Trefoil	R										
Myosotis secunda	Creeping Forget-me-not	R										
Poa annua	Annual Meadow Grass	R									R	
Prunella vulgaris	Self-heal	R										
Ranunculus flammula	Lesser Spearwort	R										
Ranunculus repens	Creeping Buttercup	F	A	A	A	O	O	A	A	A	F	F
Rumex acetosa	Common Sorrel	R										
Rumex obtusifolius	Broad-leaved Dock	R									O	
Senecio vulgaris	Ragwort	R										
Stachys palustris	Marsh woundwort	R										
Tussilago farfara	Coltsfoot	O	O						O	F	A	A
[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare. [2]Species may have been sown or could have occurred naturally.												

Table 6. Percentage ground cover (% GC), vegetation height and plant health in the Area 3 in general and in the ten quadrats studied in detail in Area 3.				
		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	100	~60	~110	Plants were generally in robust health. Most were of a normal green colour in accordance with their textbook descriptions, although some appeared very dark green indicating a soil rich in N and P. The entire area contained relatively few species.
1	100	60	120	As above
2	100	50	110	As above
3	100	45	110	As above
4	80-90	70	130	As above
5	100	80	105	As above
6	100	60	120	As above
7	100	65	130	As above
8	100	50	90	As above
9	100	50	100	As above
10	100	80	120	As above

Site 1, Area 4 (50 ha)

The area had reportedly been restored using sewage sludge (see Section 6.3 of the main report) and although most of it (labelled Area 4a for the purposes of this vegetation analysis) probably has been, there was a very species-rich area immediately south of the east/west access track (a 3 to 5 m strip of land next to the track) which is unlikely to have had sludge applications (Area 4b). Ten quadrats were examined in the area probably treated with sludge (i.e. more than 5 m south of the track) and two quadrats were examined (for comparison) in the area probably not treated with sludge.

Area 4a (lying more than 5 m south of the East/West access track) was covered in dense, species-poor, dark green vegetation which was very hard to walk through. There were few patches of bare soil and there were no legumes in this area. Species present are shown in Table 7, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail. There were few examples of species which had much ecological value in this area and the most abundant species were aggressive and of relatively low ecological value.

This was in stark contrast to the vegetation in Area 4b (which lay within 5 m of the East/West track), which was considerably more species rich. Although there were some areas of bare soil here, the area contained several legume species, some of which were frequently occurring. Although the vegetation in this area was sparse, many of the species present had value for wildlife such as insects, spiders and the larger organisms which depend on them. Species present in this part of the study area are shown in Table 8, with the DAFOR class at which they occurred overall and in the quadrats studied in detail.

Table 7. Species present in Site 1, Area 4a (area more than 5 m to the south of the east/west access track)		***DAFOR score for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Chamerion angustifolium	Rosebay Willowherb	O		O								
Chamerion angustifolium	Rosebay Willowherb	R										
Cirsium arvense	Creeping Thistle	A	A	A	A	F	A		A	A	A	D
Cirsium vulgare	Spear Thistle	R										
Deschampsia caespitosa	Tufted Hair Grass	R										
Elytrigia repens	Couch grass	F	A	F	F		F	O	F	O		O
Holcus lanatus	Yorkshire Fog	R									F	
Juncus effusus	Soft Rush	A	A	A	F		R			F	O	
Lathyrus pratensis	Meadow Vetchling	O		O	O						R	
Ranunculus repens	Creeping Buttercup	A				A	A	D	A	A	F	
Rumex obtusifolius	Broad-leaved Dock	R								O		
Salix caprea	Goat Willow	R										
Sonchus arvensis	Perennial Sowthistle	R		R								
Tussilago farfara	Coltsfoot	R					R				O	
Urtica dioica	Perennial nettle	R								O	R	
[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare.												

It is not known whether this area was sown: no written records exist of the species used, the rate at which the seed mixture was applied or the application method. It is highly unlikely that any of the species most commonly found in this area were sown, with the most frequent species being creeping thistle, couch grass, soft rush and creeping buttercup.

The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Tables 9 and 10. Most plants in the densely vegetated, species-poor Area 4a were of good health and had a size and colour consistent with their textbook descriptions, although some appeared very dark green, as though they were growing in a soil which contained high concentrations of N and P. There was no evidence of nutrient deficiency. In contrast, plants in the sparsely vegetated species-rich Area 4b were much smaller, with many appearing slightly stunted and pale.

Table 8. Species present in Site 1, Area 4b (area within 5 m of the east/west access track)		***DAFOR score for species present in whole area (W) or quadrat**		
Botanical name	**English name**	**W**	**1**	**2**
Achillea ptarmica	Sneezewort	R	O	
Anthoxanthum odoratum	Sweet Vernal Grass	O		O
Carex flacca	Glaucous sedge	R		
Cerastium fontanum	Common Mouse-ear	O	O	O
Chamerion angustifolium	Rosebay Willowherb	R		
Cirsium arvense	Creeping Thistle	R		
Crataegus monogyna	Common Hawthorn	R		
Cynosurus cristatus	Crested Dogstail	O	O	O
Dactylis glomerata	Cocksfoot	R	R	
Dactylorrhiza spp.	Orchid (not sure of species)	O	O	
Deschampsia caespitosa	Tufted Hair Grass	F	F	
Equisetum arvense	Horsetail	F	F	O
Euphrasia agg.	Eyebright	O		O
Festuca ovina	Sheep's Fescue	F	F	F
Festuca rubra	Red Fescue	F	F	F
Hieraceum agg.	Hawkweed	F		F
Holcus lanatus	Yorkshire Fog	O	O	O
Juncus bufonius	Toad Rush	R	R	
Lathyrus pratensis	Meadow Vetchling	R	R	
Linum catharticum	Fairy Flax	R		
Lotus corniculatus	Common Birdsfoot Trefoil	O	F	
Medicago lupulina	Black Medic	O		
Plantago lanceolata	Ribwort Plantain	F	F	
Prunella vulgaris	Self-heal	F		F
Ranunculus acris	Meadow Buttercup	R		
Ranunculus flammula	Lesser Spearwort	R		
Ranunculus repens	Creeping Buttercup	R	O	
Rhinanthus minor	Yellow rattle	R	O	
Salix caprea	Goat Willow	R		
Senecio jacobea	Ragwort	R		
Taraxacum agg.	Dandelion	R	O	O
Trifolium pratense	Red Clover	F	F	F
Trifolium repens	White Clover	F	O	F
Tussilago farfara	Coltsfoot	R	R	
Urtica dioica	Perennial nettle	O		
[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare.				

Table 9. Percentage ground cover (% GC)[1], vegetation height and plant health in the Area 6 in general and in the ten quadrats studied in detail in Area 4a.				
		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	100	~60	~110	Plants were generally in robust health. Most were of a normal green colour in accordance with their textbook descriptions, although some appeared very dark green indicating a soil rich in N and P. The entire area contained relatively few species.
1	100	25	60	As above
2	100	55	110	As above
3	100	50	115	As above
4	100	65	120	As above
5	100	80	140	As above
6	100	75	130	As above
7	100	70	140	As above
8	100	90	140	As above
9	100	70	130	As above
10	100	45	85	As above

Table 10. Percentage ground cover (% GC), vegetation height and plant health in Area 6 in general and in the two quadrats studied in detail in Area 4b.

		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	50	~20	~40	Plants appeared slightly pale and rather short or even stunted in some cases. The area was relatively species-rich.
1	40	15	40	As above
2	50	20	50	As above

Site 1, Area 5 (50 ha)

Plant cover in this area was almost complete, with dense growth which was often difficult to walk though. Species present in the entire area are shown in Table 11, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail. Although the authors have heard unofficially (by "word of mouth") that the area was sown, no written records have been found of the species used, the rate at which the seed mixture was applied or the application method. It is unlikely that any of the species most commonly found in this area were sown, with the most frequent species being creeping soft grass, tufted hair grass, Yorkshire fog and soft rush. Although some of the species present had value for wildlife such as insects, spiders and the larger organisms which depend on them, the most abundant species were aggressive and of relatively low ecological value.

There were almost no bare patches of soil, with vegetation cover being almost complete other than on a very few small (a few square centimetres here and there) heavily compacted patches. The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Table 12. Most plants, including the desirable species were of good health and had a size and colour consistent with their textbook descriptions. There was no evidence of nutrient deficiencies in the vegetation.

Table 11. Species present in Site 1, Area 5		***DAFOR score for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Aesculus hippocastanum	Horse Chestnut	R										
Agrostis capillaris[2]	Common Bent	O		R	O						A	
Angelica sylvestris	Wild Angelica	R	O									
Anthoxanthum odoratum[2]	Sweet Vernal Grass	O		F	A							
Anthriscus sylvestris	Cow parsley	R										
Bellis perennis	Daisy	R										
Cardamine hirsute	Hairy Bitter-cress	R										
Carex nigra	Common Sedge	R										
Carex viridula ssp. viridula	Small-fruited Yellow Sedge	R										
Centaurea nigra	Common Knapweed	R		R	F							
Cerastium fontanum	Common Mouse-ear	R		R								
Chamerion angustifolium	Rosebay Willowherb	R	A	R								
Cirsium arvense	Creeping Thistle	R						R	O		R	R
Cirsium palustre	Marsh Thistle	O		O		F						
Cirsium vulgare	Spear Thistle	R										
Crataegus monogyna	Common Hawthorn	R										
Cynosurus cristatus[2]	Crested Dogstail	R										
Dactylis glomerata[2]	Cocksfoot	R		O	R							
Dacylorrhiza spp.	Orchid (not sure of species)	R										
Deschampsia caespitosa	Tufted Hair Grass	A	A			A	A	A				
Dryopteris filix-mas	Male Fern	O										
Elytrigia repens	Couch Grass	R										
Epilobium montanum	Broad leaved Willowherb	O	R			A		O				
Epilobium palustre	Marsh Willowherb	R						R				
Equisetum arvense	Horsetail	O		R	O	R		R			R	
Festuca ovina[2]	Sheep's Fescue	O										
Festuca rubra[2]	Red Fescue	O										
Galium saxatile	Heath Bedstraw	O										
Holcus lanatus	Yorkshire Fog	A		O	A			F	F	A	F	A
Holcus mollis	Creeping Soft Grass	A	A		F							
Juncus effuses	Soft Rush	A				A	O	F				
Lathyrus pratensis	Meadow Vetchling	O	O	O	O	O		R			R	
Lolium perenne[2]	Perennial Ryegrass	R								O		
Lotus pedunculatus	Greater Birdsfoot Trefoil	F				F	A					
Molinia caerulea	Purple Moor Grass	F		O	F					O		
Phleum pratense[2]	Timothy	R			O							
Poa annua	Annual Meadow Grass	R										
Plantago lanceolata	Ribwort Plantain	F		A	F							
Potentilla erecta	Tormentil	R					O					
Ranunculus acris	Meadow Buttercup	R										
Ranunculus repens	Creeping Buttercup	F							D	F	F	R
Rhinanthus minor	Yellow rattle	R				R						
Rosa canina	Dog rose	R										
Rumex acetosa	Common Sorrel	F	F	O		O	F					O
Rumex crispus	Curled Dock	R										R
Rumex obtusifolius	Broad-leaved Dock	F						A				A
Salix caprea	Goat Willow	R										
Stellaria graminea	Lesser Stitchwort	R										
Trifolium pratense[2]	Red Clover	R										
Urtica dioica	Perennial nettle	R							O			
Vicia cracca	Tufted vetch	R						R				
[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare. [2]Species may have been sown or could have occurred naturally.												

Table 12. Percentage ground cover (% GC), vegetation height and plant health in Area 5 in general and in the ten quadrats studied in detail in Area 5.				
		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	100	~60	~100	Plants were generally in robust health. Most were of a normal green colour in accordance with their textbook descriptions. Plants on the mound slopes and top were typical of those occurring in drier locations than those on the lower-lying areas.
1	100	70	125	As above
2	100	40	90	As above
3	100	50	95	As above
4	100	70	130	As above
5	100	60	115	As above
6	100	80	135	As above
7	100	35	65	As above
8	100	55	85	As above
9	100	45	75	As above
10	100	55	110	As above

Site 1, Area 6 (50 ha)

This area had not been restored using sewage sludge, although in some parts of the area walked, which were not far from the OS grid reference, it appears as though restoration has taken place, since some ground was covered in dense, deep green vegetation which was very hard to walk through. Much of the site was species-poor and some of the species present (such as nettle and dock) tend to thrive in soils rich in N and P. This was in stark contrast to other un-restored areas at the site, which contained a wide range of species, a high percentage of bare soil and the vegetation was generally low-growing and nutrient-deficient in appearance. This area was gently south-facing and reasonably dry underfoot during our visit, although there were some wet patches at the bottom of the slope to the south of the area. It was accessed from the public road to the south east, although this approach involved rough walking for around 1 km. The area was uneven and rough in places, although it contained fewer rocks and blocks of concrete than Areas 1, 2 and 5. Due to the dense, high vegetation and presence of hidden holes and ditches, it would not be safe for the public to walk on or for livestock grazing without a certain amount of levelling. It would also require to be fenced if livestock were to be put on the land.

Vegetation cover was variable. It was often very tall and dense, but there were some patches where it was lower in height, with a few patches of species-rich flora. Forty seven species were recorded in this area, with the abundant species being tufted hair grass, creeping soft grass and soft rush. The area was variable in terms of its ecological value, with some relatively species-rich patches and some areas which were species-poor and which contained few species with relatively low ecological value. There were almost no bare areas and those which were present were only a few square cm in size. The health of the vegetation appeared generally good, with no evidence of nutrient deficiency. Most were of a normal green colour in accordance with their textbook descriptions, although some appeared very dark green indicating a soil rich in N and P. The entire area contained relatively few species. These are shown in Table 13, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail.

Although the authors have heard unofficially (by “word of mouth”) that the area was sown, no written records exist of the species used, the rate at which the seed mixture was applied or the application method. It is highly unlikely that any of the species most commonly found in this area were sown, with the most frequent species being creeping thistle, tufted hair grass, creeping soft grass, soft rush, broad-leaved dock and perennial nettle.

Table 13. Species present in Site 1, Area 6		***DAFOR score for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Agrostis capillaris[2]	Common Bent	R		O								
Anthoxanthum odoratum[2]	Sweet Vernal Grass	O	F									
Arenaria serpyllifolia	Thyme-leaved sandwort	R										
Bellis perennis	Daisy	R										
Cardamine hirsute	Hairy Bitter-cress	O								F		
Carex flacca	Glaucous sedge	R										
Carex nigra	Common Sedge	R										
Carex versicaria	Bladder Sedge	O			A							
Centaurea nigra	Common Knapweed	R										R
Cerastium fontanum	Common Mouse-ear	R		R								
Cirsium arvense	Creeping Thistle	F		F		F	F	R	F	O	O	D
Cirsium palustre	Marsh Thistle	O			O							O
Cirsium vulgare	Spear Thistle	R										
Crataegus monogyna	Hawthorn	R										
Cynosurus cristatus[2]	Crested Dogstail	R	F									
Dactylis glomerata[2]	Cocksfoot	R										
Dactylorrhiza spp.	Orchid (not sure of species)	R										
Deschampsia caespitosa	Tufted Hair Grass	A		A		F		A	A	O	A	O
Epilobium montanum	Broad leaved Willowherb	R		R						O		O
Equisetum arvense	Horsetail	O	A									
Euphrasia agg.	Eyebright	R										
Festuca ovina[2]	Sheep's Fescue	O	O									
Festuca rubra[2]	Red Fescue	R										
Hieraceum agg.	Hawkweed	R										
Holcus lanatus	Yorkshire Fog	O	F	O	O			F			O	R
Holcus mollis	Creeping Soft Grass	A				A	A	A	F			
Juncus effuses	Soft Rush	A		F	F			F		A	A	F
Lathyrus pratensis	Meadow Vetchling	O	O			O	O					
Lotus corniculatus	Common Birdsfoot Trefoil	R										
Phleum pratense[2]	Timothy	R					R		F	O		
Poa annua	Annual Meadow Grass	R										
Plantago lanceolata	Ribwort Plantain	O	O	F								
Prunella vulgaris	Self-heal	O	O	O								
Ranunculus acris	Meadow Buttercup	R										
Ranunculus flammula	Lesser Spearwort	R										
Ranunculus repens	Creeping Buttercup	O	O									
Rumex acetosa	Common Sorrel	O		F	O						O	F
Rumex crispus	Curled Dock	O				F	A					
Rumex obtusifolius	Broad-leaved Dock	F					A	O	F			
Senecio vulgaris	Ragwort	R										
Stachys palustris	Marsh woundwort	R									O	
Trifolium repens	White Clover	O	F									
Tussilago farfara	Coltsfoot	O	F					O	O			
Urtica dioica	Perennial nettle	F	O	O		F	F	F		F		
Valeriana officinalis	Valerian	O			F							
Veronica hederifolia	Ivy-leaved Speedwell	O		O								O
Vicia cracca	Tufted vetch	R		R								
[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare. [2]Species may have been sown or could have occurred naturally.												

The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Table 14.

Table 14. Percentage ground cover (% GC), vegetation height and plant health in the Area 6 in general and in the ten quadrats studied in detail in Area 6.

		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	100	~60	~110	Plants were generally in robust health. Most were of a normal green colour in accordance with their textbook descriptions, although some appeared very dark green indicating a soil rich in N and P. The entire area contained relatively few species.
1	100	25	60	Plants in this quadrat appeared distinctly paler and smaller than those in other quadrats in this area.
2	100	55	110	Plants in this quadrat had a normal appearance, indicating adequate nutrition.
3	100	50	115	As above
4	100	65	120	Plants in this quadrat appeared very dark green and vigorous (i.e. more than in other quadrats in this area).
5	100	80	140	As above
6	100	75	130	As above
7	100	70	140	Plants in this quadrat appeared very dark green and vigorous (i.e. more than in other quadrats in this area).
8	100	90	140	As above
9	100	70	130	Plants in this quadrat appeared slightly paler than those in other quadrats in this area.
10	100	45	85	Plants in this quadrat appeared slightly paler and slightly smaller than average for this area.

Appendix 5b. Full vegetation analysis (Site 2)

Site 2, Area 1 (Approximately 5 ha).

This area had been restored using sewage sludge which had been disced in (technique described in Section 7.3 of the main report). Vegetation cover was dense across almost all of the area, with only a few, small bare patches. The health of the vegetation was generally good, although some of the grasses in some quadrats looked slightly pale and deficient in N. Species present in the entire area are shown in Table 15, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail. Sown species include various cultivars of perennial ryegrass, cocksfoot, timothy and red and white clovers. Perennial ryegrass was abundant in eight quadrats, frequent in two and was abundant across the area as a whole. Cocksfoot was not recorded. Timothy was abundant in four quadrats, frequent in four and occasion in two. It was frequent across the area as a whole. Red clover was apparently absent in the area (or at least it was not flowering) and white clover was frequent. The area contained some non-sown species but in general, this sward comprised mainly sown, agriculturally useful grassland species including forage grasses and clovers. The sward was also of high ecological value, since it contained a varied mix of grasses and other flowering plants.

Table 15. Species present in Site 2, Area 1		***DAFOR class for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Agrostis capillaris	Common Bent	F	F	A	F		F	O	F	F	O	A
Agrostis stolonifera	Creeping bent	O	O				O		O	F		O
Alopecurus pratensis	Meadow Foxtail	F			O	F	O	F	F	O	O	
Cardamine hirsuta	Hairy bitter-cress	R				R						
Cerastium fontanum	Common Mouse-ear	R	R									
Festuca ovina	Sheep's Fescue	R		O								O
Festuca rubra	Red Fescue	R					O					F
Holcus lanatus	Yorkshire Fog	O					F	F	F	O	O	F
Lolium perenne[2]	Perennial Ryegrass	A	A	A	A	A	A	A	A	F	A	F
Phleum pratense[2]	Timothy	F	A	A	O	O	A	F	F	F	A	F
Plantago lanceolata	Ribwort Plantain	R										
Poa annua	Annual Meadow Grass	R				R	O	O	O		R	F
Ranunculus repens	Creeping Buttercup	R				O						
Rumex crispus	Curled dock	R					O					
Rumex obtusifolius	Broad-leaved Dock	R										
Trifolium repens[2]	White Clover	F	O	F	A	A	A	A	F	A	F	O
Tussilago farfara	Coltsfoot	R				O			O			

[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare. [2]Species was sown in Spring 2014.

The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Table 16. The ground in this area was very well covered with foliage, with much of the ground cover comprising sown species including timothy, perennial ryegrass and white clover. Most plants, including sown species were of good health and had a size and colour consistent with their textbook descriptions, although some areas of the sward were somewhat pale, indicating a likely slight shortage of N.

Table 16. Percentage ground cover (% GC), vegetation height and plant health in the Area 1 in general and in the ten quadrats studied in detail in Area 1.				
		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	90-100	~65	~90	Plants of both wild and sown species were generally in robust health. Most were of a normal green colour, but some were slightly pale, indicating a slight shortage of nutrients, especially N. The soils in this area were comparable to those in Area 2 and generally drier than those in areas 4 and 5.
1	100	35	60	As above
2	100	45	75	As above
3	90-100	35	70	As above
4	80-90	40	75	As above
5	100	40	70	As above
6	100	35	75	As above
7	100	40	65	As above
8	80-90	15	50	As above
9	90-100	30	65	As above
10	100	30	55	As above

Site 2, Area 2 (Approximately 5 ha)

This area had been restored using sewage sludge which had been disced in (technique described in Section 7.3 of the main report). Vegetation cover was dense across almost all of the area, with only a few, small bare patches. The health of the vegetation appeared generally good, although some of the grasses in some quadrats looked slightly N deficient. Species present in the entire area are shown in Table 17, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail. Sown species include various cultivars of perennial ryegrass, cocksfoot, timothy and red and white clovers. Perennial ryegrass was abundant in five quadrats, occasional in two, frequent in two and absent in one. It was abundant across the area as a whole. Cocksfoot was rarely recorded. Timothy was abundant in seven quadrats, occasional in one, frequent in one and absent in one. It was abundant across the area as a whole. Red clover was extremely rare in the area and white clover frequent. The area contained some non-sown species but in general, this sward comprised mainly sown, agriculturally useful grassland species including forage grasses and clovers. The sward was also of high ecological value, since it contained a varied mix of grasses and other flowering plants.

Table 17. Species present in Site 2, Area 2		***DAFOR class for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Agrostis capillaris	Common Bent	F	F	F	F	F	O			F	O	
Agrostis stolonifera	Creeping bent	F		O	F	O	O	O		F	F	F
Alopecurus pratensis	Meadow Foxtail	R								O		
Cirsium arvense	Creeping Thistle	O										
Cirsium palustre	Marsh Thistle	R										
Cirsium vulgare	Spear Thistle	R										
Dactylis glomerata[2]	Cocksfoot	R										
Festuca ovina	Sheep's Fescue	O					O			O	F	
Festuca rubra	Red Fescue	O				O		A			F	
Holcus lanatus	Yorkshire Fog	F	O	O	F	F		F	F	A	A	F
Juncus effusus	Soft Rush	O						F	D	O		O
Lolium perenne[2]	Perennial Ryegrass	A	F	A	A	A	A	O		A	F	O
Phleum pratense[2]	Timothy	A	A	A	A	A	A	F	O	A	A	
Poa annua	Annual Meadow Grass	R										O
Ranunculus repens	Creeping Buttercup	R										
Rumex crispus	Curled dock	R					R					
Rumex obtusifolius	Broad-leaved Dock	R										
Trifolium repens[2]	White Clover	F	F	O	O	F	O	O				F
Trifolium pratense[2]	Red clover	R										
Tussilago farfara	Coltsfoot	R										
Urtica dioica	Perennial Nettle	R										
[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare. [2]Species was sown in Spring 2014.												

The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Table 18. The ground in this area was very well covered with foliage, with much of the ground cover comprising sown species including timothy, perennial ryegrass and white clover. Most plants, including sown species were of good health and had a size and colour consistent with their textbook descriptions, although some areas of the sward were somewhat pale, indicating a likely slight shortage of N. The soils in this area were comparable to those in Area 1 and generally drier than those in Areas 4 and 5.

Table 18. Percentage ground cover (% GC), vegetation height and plant health in the Area 2 in general and in the ten quadrats studied in detail in Area 2.				
		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	100	~65	~90	Plants of both wild and sown species were generally in robust health. Most were of a normal green colour, but some were slightly pale, indicating a slight shortage of nutrients, especially N. The soils in this area were generally drier than those in areas 4 and 5.
1	100	60	90	As above
2	100	70	100	As above
3	100	65	95	As above
4	100	60	95	As above
5	100	60	80	As above
6	100	45	85	As above
7	100	110	135	As above
8	100	60	90	As above
9	100	65	90	As above
10	60-70	20	65	As above

Site 2, Area 3 (Approximately 5 ha)

This area had been restored using sewage sludge with the double digging technique described in Section 7.3 of the main report. Vegetation cover was dense across almost all of the area, with a few, small bare patches. The health of the vegetation was generally good, with little evidence of nutrient deficiency. Species present in the entire area are shown in Table 19, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail. Sown species include various cultivars of perennial ryegrass, cocksfoot, timothy and red and white clovers. Perennial ryegrass was abundant in six quadrats, frequent in two and occasional in two and was frequent across the area as a whole. Cocksfoot was rarely recorded. Timothy was abundant in four quadrats, frequent in two and occasional in four and was frequent across the area as a whole. Red clover was apparently absent but white clover was frequent. The area contained several non-sown species which thrive in relatively poor (often acid) wet soils including rushes, field woodrush, marsh thistle, creeping buttercup, various species of sedge, tufted hair grass and yorkshire fog. The sward was of moderate ecological value, since it contained a varied mix of species with no dominant or abundant species.

Table 19. Species present in Site 2, Area 3		***DAFOR class for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Agrostis capillaris	Common Bent	R				O					O	
Agrostis stolonifera	Creeping Bent	R										
Alopecurus geniculatus	Marsh Foxtail	R							R			
Alopecurus pratensis	Meadow Foxtail	R										
Anthoxanthum odoratum	Sweet Vernal Grass	R				O	O					
Carex leporina	Oval Sedge	R								R		
Carex nigra	Common Sedge	R										
Cerastium fontanum	Common Mouse-ear	R				R		R				
Cirsium palustre	Marsh Thistle	R										O
Cirsium vulgare	Spear Thistle	R										
Cynosurus cristatus	Crested Dogstail	R				R	O	F			O	
Dactylis glomerata[2]	Cocksfoot	R			O							
Deschampsia caespitosa	Tufted Hair Grass	R		O								
Epilobium montanum	Broad leaved Willowherb	R						R			R	
Equisetum arvense	Horsetail	R										
Festuca ovina	Sheep's Fescue	F					F		F	O	F	F
Festuca rubra	Red Fescue	F				O	F	O	F	O	F	
Holcus lanatus	Yorkshire Fog	F	F	F	A	O	O	O	A	F	A	A
Holcus mollis	Creeping Soft Grass	R										
Juncus articulatus	Jointed Rush	R										
Juncus effusus	Soft Rush	O						R				
Lolium perenne[2]	Perennial Ryegrass	F	A	A	F	F	A	O	A	A	A	O
Luzula campestris	Field Woodrush	R				R						
Phleum pratense[2]	Timothy	F	A	A	F	O	O	O	O	A	F	A
Ranunculus repens	Creeping Buttercup	R										
Rumex acetosa	Common Sorrel	R	R									
Sagina procumbens	Pearlwort	R						R				
Trifolium repens[2]	White Clover	F		O	O	F	F	O	O	O	F	O
Tussilago farfara	Coltsfoot	R	O									
[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare. [2]Species was sown in Spring 2014.												

The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Table 20. The ground in this area was very well covered with foliage and there were relatively few bare patches, although a significant percentage of the ground cover in some parts of the area was down to weed species rather than sown species. Most plants, including sown species were of good health and had a size and colour consistent with their textbook descriptions.

Table 20. Percentage ground cover (% GC), vegetation height and plant health in the Area 3 in general and in the ten quadrats studied in detail in Area 3.				
		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	90-100	~60	~80	Plants generally healthy in appearance, with most plants of typical size and good colour in comparison with their textbook descriptions.
1	100	60	100	As above
2	90-100	50	80	As above
3	100	45	80	As above
4	70-80	70	80	As above
5	80-90	80	90	As above
6	70-80	25	60	As above
7	100	45	70	As above
8	90-100	50	105	As above
9	100	40	90	As above
10	100	60	100	As above

Site 2, Area 4 (Approximately 5 ha)

This area had been restored using sewage sludge with the double digging technique described in Section 7.3 of the main report. Vegetation cover was dense across almost all of the area and sometimes tall (> 1 m high), with a few, small bare patches. The health of the vegetation was generally good, with little evidence of nutrient deficiency. Species present in the entire area are shown in Table 21, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail. Sown species include various cultivars of perennial ryegrass, cocksfoot, timothy and red and white clovers. Perennial ryegrass was abundant in two quadrats, occasional in four and was occasional across the area as a whole. Cocksfoot was rarely recorded. Timothy was recorded more often, red clover was rare and white clover frequent. The area contained several non-sown species which thrive in relatively poor (often acid), wet soils including soft rush, field woodrush, marsh thistle, creeping buttercup, various species of sedge, tufted hair grass and yorkshire fog. The sward was of moderate ecological value, since it contained a varied mix of species with no dominant or abundant species.

The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Table 22. The ground in this area was very well covered with foliage and there were relatively few bare patches, although a significant percentage of the ground cover in some parts of the area was down to weed species rather than sown species. Most plants, including sown species were of good health and had a size and colour consistent with their textbook descriptions.

Table 21. Species present in Site 2, Area 4		***DAFOR class for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Agrostis capillaris	Common Bent	R		O	F	F	O					
Agrostis stolonifera	Creeping Bent	O		O			O					
Alopecurus geniculatus	Marsh Foxtail	O							R		O	
Alopecurus pratensis	Meadow Foxtail	O						F	R	O	F	F
Anthoxanthum odoratum	Sweet Vernal Grass	O		O		O				O		R
Carex leporina	Oval Sedge	O										
Carex nigra	Common Sedge	R		O								
Carex pulicaris	Flea Sedge	R		O								
Cerastium fontanum	Common Mouse-ear	O										R
Cirsium palustre	Marsh Thistle	O										
Cirsium vulgare	Spear Thistle	O										
Cynosurus cristatus	Crested Dogstail	R							R			
Dactylis glomerata[2]	Cocksfoot	R										
Deschampsia caespitosa	Tufted Hair Grass	O				F				O		
Equisetum arvense	Horsetail	R										
Festuca ovina	Sheep's Fescue	R										
Festuca rubra	Red Fescue	O	F	O	O				O			
Holcus lanatus	Yorkshire Fog	F	F		O	O	O	A	F	F	A	A
Holcus mollis	Creeping Soft Grass	R				O						O
Juncus articulatus	Jointed Rush	R										
Juncus effusus	Soft Rush	F	A				A		O	O		O
Lolium perenne[2]	Perennial Ryegrass	F		O	F	F		A	F	F		F
Phleum pratense[2]	Timothy	F			R	O			R	O	O	F
Ranunculus repens	Creeping Buttercup	O							O	F	O	F
Sagina procumbens	Pearlwort	R										
Trifolium pratense[2]	Red Clover	R										
Trifolium repens[2]	White Clover	O	R	F	F	O		R	O			F
Tussilago farfara	Coltsfoot	R										
[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare. [2]Species was sown in 2014.												

Table 22. Percentage ground cover (% GC), vegetation height and plant health in the Area 4 in general and in the ten quadrats studied in detail in Area 4.				
		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	90-100	~60	~90	Plants generally healthy in appearance, with most plants of typical size and good colour in comparison with their textbook descriptions.
1	100	90	130	As above
2	50-60	12	50	As above
3	80-90	28	62	As above
4	100	60	112	As above
5	100	90	140	As above
6	100	60	80	As above
7	80-90	50	120	As above
8	100	65	110	As above
9	100	40	60	As above
10	100	50	80	As above

Site 2, Area 5 (Approximately 5 ha)

This area had been restored using sewage sludge with the double digging technique described in Section 7.3 of the main report. Vegetation cover was dense across almost all of the area, with a few, small bare patches. The sward was of moderate ecological value, since it contained a varied mix of species with no dominant or abundant species. The health of the vegetation appeared generally good, with little evidence of nutrient deficiency. Species present in the entire area are shown in Table 23, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail.

Table 23. Species present in Site 2, Area 5		***DAFOR class for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Agrostis capillaris	Common Bent	F						F	F	F	O	R
Agrostis stolonifera	Creeping bent	F						F	F	F	O	
Anthoxanthum odoratum	Sweet Vernal Grass	O			O					O	O	
Carex leporina	Oval Sedge	R										
Carex nigra	Common Sedge	R							R		O	
Carex pulicaris	Flea Sedge	R										
Cirsium palustre	Marsh Thistle	O										
Cirsium vulgare	Spear Thistle	R										
Dactylis glomerata[2]	Cocksfoot	R										
Deschampsia caespitosa	Tufted Hair Grass	O							R			O
Elymus repens	Couch Grass	O					F					
Equisetum arvense	Horsetail	R	R	R		R						
Festuca ovina	Sheep's Fescue	O		O			F					
Festuca rubra	Red Fescue	F	O			O		F		F		F
Holcus lanatus	Yorkshire Fog	F		F	F	A	F	O	O	O		F
Juncus effusus	Soft Rush	F		O	O		A		R	R	A	F
Lolium perenne[2]	Perennial Ryegrass	O	A			A	O	O	O	O		
Luzula campestris	Field Woodrush	R	R									
Phleum pratense[2]	Timothy	O	R	O	O	F	R	R				
Potentilla erecta	Tormentil	R									R	
Ranunculus repens	Creeping Buttercup	R		F				O	F			
Sagina procumbens	Pearlwort	R										
Stellaria graminea	Lesser Stitchwort	R					R					
Trifolium repens[2]	White Clover	F	F	F	O	O		O	O			F
Trifolium pratense[2]	Red clover	R										
Tussilago farfara	Coltsfoot	R										
[1]Shaded square indicates species not present in quadrat; DAFOR SCORE: D=dominant; A=abundant; F=frequent; O=occasional; R=rare. [2]Species was sown in 2014.												

Sown species include various cultivars of perennial ryegrass, cocksfoot, timothy and red and white clovers. Perennial ryegrass was abundant in two quadrats, occasional in four and was occasional across the area as a whole. Cocksfoot was rarely recorded. Timothy was recorded much more often, red clover was rare and white clover frequent. The area contained several non-sown species which thrive in relatively poor (often acid) wet soils including soft rush, field woodrush, marsh thistle, creeping buttercup, various species of sedge, tufted hair grass and yorkshire fog.

The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Table 24. The ground in this area was very well covered with foliage, although a significant percentage of the ground cover in some parts of the area was down to weed species rather than sown species. Most plants, including sown species were of good health and had a size and colour consistent with their textbook descriptions.

Table 24. Percentage ground cover (% GC), vegetation height and plant health in the Area 5 in general and in the ten quadrats studied in detail in Area 5.				
		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	~10	~10	45	Plants of both wild and sown species were generally in robust health and were of normal green colour. There was no evidence of nutrient deficiencies. The soils in much of the area were fairly wet and it was little surprise that several species which thrive in wet conditions were growing strongly and were often frequent in quadrats.
1	90-100	15	60	Ground very wet in this quadrat.
2	100	25	70	As above
3	100	30	60	As above
4	100	50	70	As above
5	100	55	110	As above
6	90-100	30	60	Ground less wet than in some areas. Some bare patches
7	80-90	15	60	As above
8	70-80	35	90	As above
9	60-70	40	90	As above
10	100	35	120	Ground very wet in this quadrat.

Site 2, Area 6 (Approximately 5 ha)

This area was as yet un-restored. The soil has not been ripped or cultivated and no sewage sludge or other organic materials have been applied (Section 7.3). It had not been deliberately sown and the species present had all arrived naturally. Vegetation cover was very sparse cross much of the area and much of the soil was bare, though there were some patches where species typical of waste land were growing, albeit not vigorously. The sward was of poor ecological value, since the topsoil substitute had very few plants growing on it. Species present in the entire area are shown in Table 25, with the DAFOR class at which they occurred overall and in the ten quadrats studied in detail.

The percentage cover within each quadrat, the mean and maximum height of the vegetation and the general condition of the plants present are summarised in Table 26. Plants in area six were generally very small in comparison with their textbook descriptions and often had a pale or purple colour, indicating general nutrient deficiency.

Table 25. Species present in Site 2, Area 6		***DAFOR class for species present in whole area (W) or quadrat**										
Botanical name	**English name**	**W**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Agrostis capillaris	Common Bent	R										R
Alopecurus geniculatus	Marsh Foxtail	O					R					
Alopecurus pratensis	Meadow Foxtail	O					F	O		R	O	R
Bellis perennis	Daisy	R										
Cardamine flexuosa	Wavy Bitter-cress	R									R	
Carex leporine	Oval Sedge	O										
Cerastium fontanum	Common Mouse-ear	O		O					R	R	R	
Chamerion angustifolium	Rosebay Willowherb	R										
Cirsium arvense	Creeping Thistle	O										R
Cirsium palustre	Marsh Thistle	O										
Cirsium vulgare	Spear Thistle	O										
Deschampsia caespitose	Tufted Hair Grass	O										
Epilobium brunnescens	New Zealand Willowherb	O									R	
Epilobium montanum	Broad leaved Willowherb	O										
Galium uliginosum	Fen Bedstraw	R										R
Gnaphalium uliginosum	Marsh Cudweed	R										
Hieraceum agg.	Hawkweed	R										R
Holcus lanatus	Yorkshire Fog	A		F	R	R	F		R	F	F	O
Juncus articulates	Jointed Rush	R										R
Juncus bufonius	Toad Rush	R										R
Juncus effusus	Soft Rush	O								R		O
Lolium perenne	Perennial Ryegrass	R		F	F	F	O	F	F	A	F	
Luzula campestris	Field woodrush	R										R
Myosotis laxa	Tufted Forget-me-not	R										
Poa annua	Annual Meadow Grass	O	F	F	F	O	O		R	O	O	R
Picea sitchensis	Sitka Spruce	R										
Plantago lanceolata	Ribwort Plantain	O									O	
Polygonum aviculare	Knotgrass	R									R	
Polygonum maculosa	Redshank	O									F	
Potentilla anserine	Silverweed	R										
Potentilla erecta	Tormentil	O										
Prunella vulgaris	Self-heal	O										
Ranunculus flammula	Lesser Spearwort	R										
Ranunculus repens	Creeping Buttercup	O		R			R	O		O		O
Rubia peregrina	Wild Madder	R										
Rumex acetosa	Common Sorrel	R										
Sagina procumbens	Pearlwort	O			R		R				O	
Salix caprea	Goat Willow	R										
Senecio jacobea	Ragwort	O										
Taraxacum agg.	Dandelion	O										
Trifolium pratense	Red Clover	R										
Trifolium repens	White Clover	O						R		R	R	
Tripleurospermum inodorum	Scentless Mayweed	R									R	
Tussilago farfara	Coltsfoot	A		F				O	A			F
Veronica serpyllifolia	Thyme-leaved speedwell	R		R						R	R	
*Shaded square indicates species not present in quadrat; DAFOR class: D=dominant; A=abundant; F=frequent; O=occasional; R=rare.												

Table 26. Percentage ground cover (% GC), vegetation height and plant health in the Area 6 in general and in the ten quadrats studied in detail in Area 6.				
		Vegetation height (cm)		
Quadrat no.	**% GC**	**Mean**	**Max.**	**Comments on plant appearance/health**
Overall area	~10	~10	45	Plants generally nutrient deficient in appearance and many examples of most species appeared stunted in comparison with their textbook descriptions and their appearance in more fertile, better developed soils.
1	10-20	3	5	Nutrient deficient (pale in colour, some with a stunted appearance)
2	20-30	15	45	As above
3	0-10	4	30	As above
4	0-10	4	16	As above
5	0-10	10	34	As above
6	0-10	3	17	As above
7	10-20	5	24	As above, but slightly greener and less stunted than above
8	20-30	9	43	As above
9	30-40	7	22	As above
10	30-40	14	49	As above

Appendices 6a and 6b. Photographs of vegetation (Site 1 and Site 2)

Appendix 6a. Photographs of vegetation (Site 1)

Plate 1. Site 1, Area 1, showing one of the better parts of the area, with a few hawthorn trees and grasses of low forage value (mainly Yorkshire fog and tufted hair grass).

Plate 2. Site 1, Area 2, showing dense growth of willowherbs and weed grasses such as yorkshire fog, creeping soft grass and tufted hair grass).

Plate 3. Site 1, Area 3, showing evidence of bare patches, along with dense growth of weedy species of low forage value such as yorkshire fog, creeping soft grass and tufted hair grass.

Plate 4. Site 1, Area 4b, showing tall, dense growth of creeping thistle and couch grass.

Plate 5. Site 1, Area 5, showing the growth of creeping buttercup, Yorkshire fog, dock and other weed species of low forage value on heavily compacted, wet ground.

Plate 6. Site 1, Area 6, showing dense growth of soft rush on damp, heavily compacted ground.

Appendix 6b. Photographs of vegetation (Site 2)

Plate 1. Site 2, Area 1, showing excellent cover of sown grass and clover species.

Plate 2. Site 2, Area 2, showing good growth of sown grass species with some white clover.

Plate 3. Site 2, Area 3, showing the predominance of sown pasture grasses in a sward which contains some aggressive weeds and is in need of further management to improve sward quality.

Plate 4. Site 2, Area 4, showing the predominance of soft rush in some parts, where they are beginning to outcompete the sown grasses.

Plate 5. Site 2, Area 5, showing small patches of bare, compacted ground, a few creeping buttercups and some soft rush in amongst the sown pasture grasses.

Plate 6. Site 2, Area 6, showing limited growth of pale stunted weed species (predominantly coltsfoot in this picture) on damp, heavily compacted ground.