Materials to Land Phase 2

Technical Report

Environment Agency

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Executive Summary

Landspreading of certain materials is a waste recovery activity that can beneficially add organic matter to soil and reduce reliance on manufactured fertilisers and quarried soil conditioners. However, there are concerns that some landspreading activities are not being conducted in accordance with the applicable permits and guidance, are using this approach as a disposal route rather than an opportunity to beneficially recover and reuse waste (or waste derived) materials, and are resulting in potential harm to the environment. There is also intelligence to suggest hazards present in the materials are more complex than previously assumed at the time of development of the current regulatory mechanisms that control landspreading.

In 2015/16, AECOM completed Phase 1 of the Materials to Land (M2L) project on behalf of the Environment Agency (EA). The M2L project was part of a larger programme of investigation of the potential risks associated with wastes conducted under the overarching Waste Enforcement Programme (WEP).

The data gathered during Phase 1 of the project provided a snapshot of landspreading activities in England being carried out under mobile plant permits. Following on from Phase 1, the following aims and objectives were identified for Phase 2 of the Materials to Land project:

·   provide an assessment of materials being spread to land, using information gained through the wider Waste Enforcement Programme (WEP) in order to better ascertain the risk to human health and the wider environment from their use;

·   provide information to support a wider review of the regulations around the treatment and use of sewage sludge as a material spread to land;

·   provide information to support a planned consultation on revisions to the exemptions under the Environmental Permitting Regulations (EPR);

·   create recommendations for improvements in how waste derived materials spread to land are regulated, described, used, and compared to organic and manufactured or quarried fertiliser and soil conditioners; and

·   utilise the information obtained to inform the EA, government, and industry about the benefits and risks associated with using waste derived materials on land.

In order to meet the aims and objectives outlined above, the following scope of works was completed between January and June 2017:

·   site audits, sampling, laboratory analysis and assessment of two waste materials:

–   sewage sludge treated with lime (eight sites); and

–   pig and poultry carcass ash from pig farms (nine sites) and poultry farms (11 sites); plus

·   review of data from Phase 1 of M2L, the wider WEP programme and associated studies, including the UK water industry's Chemical Investigation Programme (CIP) with the aim of delivering a comprehensive picture of the landspreading sector, performance and risk.

In summary, the WEP and M2L projects have included the sampling of numerous waste streams plus, where possible, the fields where the waste has been spread. The samples were taken at, or close to, the place of waste application. The collated data provides insights into the range of potential contaminants in waste that could pose a risk to human health and the wider environment. These substances include both those routinely tested for in waste analysis, such as potentially toxic elements (PTEs), but also many organic pollutants including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs)and compounds of emerging concern such as Per- and Polyfluoroalkylated Substances (PFAS) and antimicrobial chemicals. Risks from these chemicals have been reviewed against existing and proposed standards and using methodologies being implemented by regulators.

The key findings of the Materials to Land Phase 2 project are summarised below:

- **Changes in Landspreading**

  - the nature and type of landspreading activities currently being undertaken in England and Wales have changed and evolved considerably since the introduction of the current permitting regime in 2010;

  - the nature of the wastes being spread is becoming increasingly complex, marking a move away from relatively well characterised single waste streams from recognised suppliers, to more complex, mixed waste streams;

  - the number of parties involved in waste spreading has also changed, moving away from a simple transparent chain comprising the producer, waste operator and farmer, to longer and more convoluted chains which can include a number of different middleman including waste brokers, contractors and subcontractors;

  - with the increased complexity, it is becoming more difficult to track wastes from the place of production to the receiving fields. There is also an increased opportunity for mistakes to arise, with an associated increased risk associated with landspreading, including spreading of materials which are not compatible with regulations, do not confer benefit, and also potentially being spread to land as this represents a more convenient and cost effective method of waste disposal;

  - the role of the EA in effectively regulating landspreading activities is becoming more difficult, with increased time pressures and reduced budgets leaving less time for staff to review each permit application;

  - at the same time, there is evidence of an increasing number of waste streams being diverted from to facilities that operate in accordance with Quality Protocols, such as composting and anaerobic digestion, where the resulting material can be spread to land with less regulatory oversight, again increasing the potential risks to the landbank from landspreading of these materials.

- **Changes in Waste Composition**

  - due to reductions in heavy industry, coupled with changes in intensive farming practices, advances in pharmaceutical and healthcare fields and the wide array of chemicals now present in everyday household products, the nature and composition of waste streams are changing. When the spreading of sewage sludge was first investigated in the 1980's, the contaminants of concern associated with sewage sludge were restricted to a simple list of selected metals and fluoride;

  - technological advances in analytical methods have allowed the detection of contaminants at lower and lower levels. This has led to the identification of a wider range of contaminants in wastes, soils, crops, livestock and the human food chain which were previously unidentified;

  - as our understanding of the behaviour and longevity of some contaminants in the natural environment has improved the number of potential contaminants present in wastes and soils, which may pose a risk to human health and the wider environment, has expanded. It now includes asbestos, PAHs, PCBs, dioxins and furans, phthalates, PFAS, antibiotics, human and veterinary medicines, pesticides, and antimicrobial chemicals;

  - in addition to chemical constituents of waste, there are also concerns over physical contaminants particularly with regard to plastics and microplastics; and

  - the fate and behaviour of many of these compounds in the soil environment are only beginning to be investigated, and the risks associated with these contaminants are not yet understood. Current testing suites for characterising wastes and soils remain largely unchanged since the introduction of SUiAR, despite increasing evidence of the identification of low levels of contaminants in waste streams. There are uncertainties over the levels of these contaminants present in wastes spread to land: specifically, whether these contaminants pose a risk to human health and the wider environment, either at the levels present in wastes or through enrichment in soils due to repeated applications over successive years.

1.   Introduction

1.1   Background

Landspreading of certain materials is a waste recovery activity that can beneficially add organic matter to soil and reduce reliance on manufactured fertilisers and quarried soil conditioners. However, there are concerns that some landspreading activities are not being conducted in accordance with the applicable permits and guidance, are using this approach as a disposal route rather than an opportunity to beneficially recover and reuse waste (or waste derived) materials, and are resulting in potential harm to the environment. There is also intelligence to suggest hazards present in the materials are more complex than previously assumed at the time of development of the current regulatory mechanisms that control landspreading.

1.1   Project Context

In 2015/16, AECOM completed Phase 1 of the Materials to Land (M2L) project on behalf of the Environment Agency (EA). The scope of works for Phase 1 included:

1. Site inspections, with sampling of both the imported waste and land on which it would be spread, for 59 landspreading activities;

2. Desk assessment of 48 approved mobile plant deployment applications for landspreading;

3. Desk assessment (using MANNNER NPK) of 24 approved mobile plant deployments involving spreading of high readily available nitrogen containing waste in or near nitrate safeguard zones protective of water wells; and

4. Collation of 31 landspreading case studies from Environment Agency staff.

The data gathered during Phase 1 of the project provided a snapshot of landspreading activities in England being carried out under mobile plant permits.

The M2L project was part of a larger programme of investigation of the potential risks associated with wastes conducted under the overarching Waste Enforcement Program (WEP).

The key findings of Phase 1 included:

· identification of the evolving nature of landspreading activities to include complex mixtures of waste, and involving waste streams from more diverse sources, making assessment of the benefit and potential harm extremely challenging;

· a change in the composition of the waste to include a greater range of potential contaminants including polychlorinated biphenyls (PCBs), dioxins and furans and "emerging toxics" such as triclosan. The risks to the environment and landbank from these potential contaminants are poorly understood; and

· evidence that poor storage, management and spreading of wastes are impacting the environment, human health and the landbank.

In the light of the findings, recommendations from Phase 1 included:

· improvements to the current ways of working to focus regulatory effort on controlling the higher risk spreading activities;

· streamlining and clarifying the permitting process to provide greater transparency on the life cycle of wastes from source to field; and

· additional investigation of potential risks associated with other landspreading activities not assessed during Phase 1, including those carried out under exemptions, quality protocol or end of waste opinions, and the Sludge (Use in Agriculture) Regulations (SUiAR).

Further funding was secured for Phase 2 of the M2L project to help reduce the uncertainty for industry and regulators (including the Food Standards Agency (FSA) and the Animal and Plant Health Agency (APHA)) around the agronomic benefits and environmental risks created by using waste on land.

1.2   Project Aims and Objectives

Following on from the findings of Phase 1, the following aims and objectives were identified for Phase 2 of the Materials to Land project:

- to provide an assessment of new and existing materials being spread to land, using information gained through the wider Waste Enforcement Program (WEP) in order to better ascertain the risk to human health and the wider environment from their use;

- to provide information to support a wider review of the regulations around the treatment and use of sewage sludge;

- to provide information to support a planned consultation on revisions to the exemptions under the Environmental Permitting Regulations (EPR);

- to create recommendations for improvements in how waste derived materials spread to land are regulated, described, used, and compared to organic and manufactured or quarried fertiliser and soil conditioners; and

- to utilise the information obtained to inform EA, government, and industry about the benefits and risks associated with using waste derived materials on land.

1.3   Scope of Work

In order to meet the aims and objectives outlined above, the following scope of works was completed.

1.3.1   Site Audits, Sampling and Data Interpretation

This task comprised development of a sampling strategy and collection of samples of two waste materials: i) sewage sludge treated with lime and ii) carcass ash from pig and poultry farms. Samples were analysed for a range of potential contaminants, and the associated risks from the spreading of these materials were assessed.

1.3.2   Review of Data from Phase 1 and Associated Projects

The data review task comprised review and interpretation of the data that resulted from the Phase 1 M2L study, plus data resulting from other associated projects conducted under the WEP in 2015/16 and Phase 2 of the M2L study, with the aim of delivering a comprehensive picture of the sector, performance and risk.

1.4   Report Structure

The report is structured as detailed below:

- Section 2 sets out the regulatory regimes for current landspreading activities;

- Section 3 summarises the findings of Materials to Land Phase 1, along with the findings of the Biowaste Treatment project and Sampling Wastes at Landfills and Deposit For Recovery (DfR) sites;

- Section 4 presents the findings of the Phase 2 site audits and sampling of pig/poultry ash and sewage sludge treated with lime;

- Section 5 summarises the analytical data and compares it to data from other published research;

- Section 6 reviews the identified risks associated with landspreading; and

- Section 7 presents the conclusions and recommendations produced by this project.

2.   Regulation and Control of Waste to Land Activities

2.1   Introduction

There are a number of routes whereby waste is applied to land, either directly or following some form of pre-treatment. These routes are collectively classed as R10 recovery operations under the EU Waste Framework Directive (2008/98/EC), i.e. "Land treatment resulting in benefit to agriculture or ecological improvement".

Waste management operations are primarily regulated under the Environmental Permitting (England and Wales) Regulations 2010, which apply to sites where waste is recycled, stored, treated, recovered, or disposed of, and to mobile plant that is designed to carry out such operations.

Waste activities may meet the Environmental Permitting Regulations (EPR) requirements by one of the following means:

·   regulatory position statement – the EA doesn't currently require a permit for the activity;

·   exemption – a permit is not required for the activity, the exemption must be registered with the Environment Agency;

·   standard rules permit – a set of fixed rules for common activities, which require a permit to be authorised by the EA; and

·   bespoke permit – tailored to the specific activity being carried out, and require authorisation by the EA.

The routes that are assessed in this report and the main regulations under which they are controlled are:

·   land spreading of waste under a Mobile Plant Licence granted under the EPR;

·   biological, chemical and physical treatment of non-hazardous sludge at a specified location under the EPR (SR2008 No.19);

·   deposit of waste for recovery, under the EPR;

·   biotreatment followed by application of the resulting compost or digestate to land. Provided the biotreatment facility follows the relevant Quality Protocol (PAS100 for composts and PAS110 for anaerobic digestates), the resulting outputs may achieve end-of-waste status and hence are no longer considered a waste;

·   spreading of sewage sludge to land under the Sludge (Use in Agriculture) Regulations (SUiAR); and

·   spreading of pig and poultry carcass ash to land, which falls under the U15 Exemption of the EPR.

2.2   Existing Regulatory Framework

2.2.1   Land Spreading under Mobile Plant Licence

Under EPR, mobile plant permits can be granted that allow an operator of mobile plant to use waste to undertake land treatment activities that result in benefit to agriculture or ecological improvement. The mobile plant permits include:

·   standard rules (SR) SR2010No4: Mobile plant for landspreading (land treatment resulting in benefit to agriculture or ecological improvement);

·   standard rules SR2010No5: Mobile plant for reclamation, restoration or improvement of land; and

·   standard rules SR2010No6: Mobile plant for landspreading of sewage sludge (land treatment resulting in benefit);

- bespoke mobile plant permits for landspreading activities that do not meet the Rules under the standard rules permits.

Each mobile plant permit defines the types of waste and quantities that can be landspread and stored prior to spreading and the maximum duration for storage. Under standard rules mobile plant permits, the permitted waste types are defined by their List of Wastes (LOW) code and associated descriptions. The waste description is important as it may relate to a specific waste stream within a broader range of wastes covered by a single LOW code. The permit also describes specific conditions for waste storage and landspreading operations and controls over emissions.

Before a particular landspreading activity can be undertaken under a mobile plant permit, an application for deployment has to be submitted to the EA. The application for deployment is assessed by the EA and, if approved, the landspreading activity can be undertaken.

The application for deployment contains the specific details about the waste types that will be spread, the receiving land and the agricultural or ecological benefit that will be achieved. It also requires the operator to assess the risks posed by the landspreading activity and how they will be managed. A single application for deployment can include up to 10 waste streams over an area of land up to 50 hectares, with the exception of 100 hectares for a single continuously managed area of land.

The application for deployment has to include a chemical analysis of the waste and receiving soil and an agricultural or ecological benefit statement written by a person with appropriate technical expertise. Appropriate expertise includes a degree in agriculture and/or people who hold a Certificate of Competence in Fertiliser Advice with the Fertiliser Advisors Certification and Training Scheme (FACTS). The benefit statement must demonstrate that the activity is a waste recovery operation (and not disposal) and must take account of the soil type and condition, the cropping cycle and requirements of the benefitting crop, as well as the nutrients and contaminants contained within the waste and receiving soil.

2.2.2   Deposit of Waste for Recovery

Deposit for recovery (DfR) occurs when an operator replaces non-waste material they would have used with a waste material that performs the same function, for construction, reclamation, restoration or improvement of land other than by mobile plant. DfR requires an Environmental Permit, which can be either a Standard Rules or Bespoke permit, and the permit application must be supported by a Waste Recovery Plan. The operator must establish and follow waste acceptance procedures. Operators who plan to use waste to grow plants and are applying for a bespoke permit may need to submit an agricultural benefit statement and/or ecological improvement statement to support the permit application.

2.2.3   Waste Exemptions

Where specific conditions can be met, waste materials may be spread to land under a registered exemption from Environmental Permitting. Exemptions generally apply to lower risk activities than those allowed under a mobile plant permit. The risk is controlled through defining and limiting the waste types and quantities that can be stored or spread to land. The key exemptions for using waste for landspreading are:

- U10 – Spreading waste to benefit agricultural land; covers spreading of specific materials to land in lieu of fertilisers including chalk, sludge, water and effluent and soil from fruit and vegetable cleaning, wood chip ash, dredging spoil, selected composts, digestates biofilter material and milk;

- U11 – Spreading waste to benefit non-agricultural land; covers spreading of a subset of the materials listed above for conferring benefit to non-agricultural land;

- U14 – Incorporating ash into soil; relates to spreading and mixing of ash back into the soil to return some of the nutrients from burnt crops and vegetation back to the soil; and

- U15 – Mixing ash from burning pig or poultry carcasses with slurry and/or manure to spread on farmland to provide the soil with nutrients.

Of these four exemptions, the U15 exemption is of most relevance to this project and is discussed in more detail below.

2.2.4   Spreading of Pig and Poultry Ash under an Exemption

Incinerators are used on farms as a method of disposing of dead livestock. The incineration of animal carcasses is controlled by the Animal By-Product Regulations (ABPR) and requires use of an approved incinerator.

The spreading of pig and poultry carcass ash on land where the animals died and were incinerated is exempted from EPR under the U15 exemption.

Under the U15 exemption, the operator is allowed to:

·   mix manure or slurry with ash from the incineration of pig and poultry carcasses;

·   spread the manure/slurry ash mix on their farm to benefit the soil; and

·   store the ash before mixing it with the manure or slurry, and store the manure/slurry ash mix before spreading it.

The operator is not allowed to:

·   take ash from neighbouring farms and mix it with manure and slurry on the operator's farm;

·   mix any other ashes with manure and slurry and spread the mix on the operator's land; or

·   plough ash straight into the soil.

The only permitted waste that can be spread under this exemption is EWC 19 01 12 (ash from the incineration of pig and poultry carcasses only).

The maximum amount of ash that can be spread under this exemption is 150kg per hectare in a 12-month period. The amount spread is limited to an amount that the soil needs, and application of more ash than appears reasonable may considered a waste disposal operation.

The following restrictions apply:

·   ash cannot be stored or spread within 10 metres of a watercourse or 50 metres of a spring, well or borehole;

·   ash must be mixed with an equal or larger amount of manure or slurry before spreading;

·   ash must be stored in a secure place before it is spread;

·   when ash is spread, the land must not have been frozen for 12 hours or more in the preceding 24 hours; and

·   the land must not be frozen, waterlogged or covered by snow.

The pig and poultry carcasses must be incinerated in compliance with the ABPR. This exemption can only take place on the same farm where the pigs or poultry died and were then incinerated.

2.2.5   Spreading of Sewage Sludge under the Sludge (Use in Agriculture) Regulations

In England, rules for spreading sewage sludge to land are detailed in the following:

·   The Sludge (Use in Agriculture) Regulations 1989 (Statutory Instruments 1989 No. 1263); and

·   The Sludge (Use in Agriculture) (Amendment) Regulations 1990 (Statutory Instruments 1990 No. 880).

These two pieces of legislation implemented the requirements of the EU Directive (86 / 278 / EEC) on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture.

Subsequent changes to other legislation have also amended the requirements of The Sludge (Use in Agriculture) Regulations 1989, including The Environmental Civil Sanctions (Miscellaneous Amendments) (England) Regulations 2010 (Statutory Instruments No. 1159) and The Waste Management Licensing (England and Wales) (Amendment and Related Provisions) (No. 3) Regulations 2005 (Statutory Instruments No. 1728).

The regulations and subsequent amendments and guidance set out requirements for the application of sludge to agricultural land. Limit values for potentially toxic elements (PTE) in the sewage sludge and the soil are stated and require assessment based on proposed application rates and the benefit and risks to crops, soil and the wider environment.

The Sludge (Use in Agriculture) Regulations (SUiAR) allow the spreading of sewage sludge and septic tank onto agricultural land. For the purposes of SUiAR, agriculture has a narrow definition, meaning, "*growing of all types of commercial food crops, including for stock-rearing purposes*". An Exemption (the S3 exemption) exists under the EPR for the storage of sewage sludge at the agricultural field where it will be spread.

Sewage sludge is the residual sludge from wastewater treatment works (WwTW) treating domestic or urban wastewaters. The bulk of its content derives from mainly human wastes but there are also discharges to sewer of industrial effluent, animal and food processing wastes and storm water from roads and pavements. Therefore, in addition to organic waste material there are traces of other substances, some of which can be toxic to humans and animals at elevated concentrations in the soil or in food. The composition of sludge is thought to be becoming increasingly complex given the relative decrease in traditional inputs (e.g. from heavy industry) and a relative increase from domestic sources and stormwater.

Smith (2009) identified the following compounds, which may be incorporated in sewage sludge:

· persistent compounds from incomplete combustion of fossil fuels that enter the urban wastewater collection system through deposition onto paved surfaces via run-off (e.g. polycyclic aromatic hydrocarbons (PAHs) and dioxins / furans);

· persistent compounds that are associated with impurities in wood preservatives such as creosote (PAHs) and pentachlorophenol (PCP) that enter urban wastewater in run-off;

· controlled persistent compounds mobilized by volatilisation from soil, deposition and transfer to urban wastewater in run-off (e.g. PAHs, PCBs and dioxins / furans);

· persistent compounds generated by cooking food that are discharged from domestic sources (e.g. PAHs);

· persistent compounds that are prohibited from use/manufacture, but domestic sources may exist and can transfer to urban wastewater via run-off (e.g. chlorinated pesticides);

· compounds discharged to sewer used directly in industrial processes or domestically, including solvents, flame retardants or compounds that leach from plastics and surfaces during end-use and are carried in run-off (e.g. di(2-ethylhexyl)phthalate (DEHP) and polybrominated diphenyl ethers (PBDEs));

· detergent residues (e.g. linear alkylbenzene sulphonates, nonylphenol and nonylphenol ethoxylates);

· pharmaceuticals, antibiotics, endogenous hormones and synthetic steroids; and,

· compounds from the various above groups with endocrine-disrupting potential.

Microplastics are also a growing concern. These can be split into two groups (CIWEM, 2017):

· primary microplastics include industrial scrubbers used in blast cleaning, plastic powders used in moulding, nanoparticles used in industrial processes and micro-beads used in cosmetics and personal care products. Soaps are a major source of microbeads both in personal care products (e.g. deodorant, shampoo, conditioner, shower gel, lipstick, hair colouring, shaving cream, sunscreen, insect repellent, anti-wrinkle creams, moisturizers, hair spray, facial masks, baby care products, eye shadow, mascara) and in detergents for washing machines; and

· secondary microplastics formed by fragmentation and weathering of larger plastic items during the use of products such as textiles (including microfleece materials), paint and tyres, or once these or other plastic items (bags, bottles etc.) have been released into the environment.

Most microplastic emissions occur in urban and residential areas. In developed regions, municipal/industrial effluents and even diffuse urban runoff are eventually conveyed to wastewater treatment works. Additives used in manufacture include, PCBs, polybrominated diphenyl ethers (PBDEs), perfluorooctanoic acid (PFOA), bis-phenol A (BPA) and phthalate plasticisers. Microplastics could also provide a medium for exotic species and pathogens, for example microorganisms developing biofilms on microplastics particles. (UNEP, 2015).

During wastewater treatment, over 90% of microplastics are retained in sewage sludge (Carr, 2016). Most of the plastic ingredients in microplastics contain non-degradable polymers, which may take hundreds of years to degrade completely via oxidative or photodegradation routes (UNEP, 2015).

In most urban and domestic environments, the contact time for these chemicals with human users will be in the order of minutes to days, with most of the chemical residues following usage being washed into sewers. However, once partitioned into sludge and spread to land, the residence time for some of the more persistent chemicals in agricultural soils can be many years.

Sludge also contains bacteria and viruses, which are a potential hazard to the health of humans, animals and plants.

Where sludge is used in agriculture these risks, and its rate of application to the soil, is controlled by the SUiAR, Defra Code of Practice for Agriculture use of Sewage Sludge, Agricultural Development and Advisory Service (ADAS) Safe Sludge Matrix (voluntary agreement) and ADAS Nutrient Management Matrix (voluntary agreement). Since 1999, the use of raw untreated sewage sludge has been phased out and a range of biological, chemical, heat treatment and storage processes are now used to treat sludge, to reduce its fermentability and health hazard.

The majority of sewage sludge is treated at WwTW where it is generated, and then spread directly to land. Sludge, which is not treated at the WwTW, can also be treated by lime stabilisation, which is recognised as an effective chemical treatment process, which involves mixing lime materials with sewage sludge. The lime stabilisation of liquid sludge treatment process is described in the Defra Code of Practice for Agriculture Use of Sewage Sludge as the '*Addition of lime to raise the pH greater than 12.0 and sufficient to ensure that the pH is not less than 12 for a minimum period of 2 hours.*' The purpose of maintaining the alkaline pH is to reduce the activity of pathogenic bacteria within the sludge, particularly E. coli, and salmonella.

This lime stabilisation process is often contracted out to third party operators, typically on agricultural holdings. If the mixture of sludge and lime has a pH of 12 or higher for a period greater than 2 hours, it can be used as treated sludge directly on agricultural land.

A crucial component of the SUiAR is the requirement for the sludge producer to keep up to date records of the following:

· volume of sludge produced, and supplied to farms;

· results of sludge analysis;

· method of treatment; and

· results of soil analysis.

Records, which should be provided to the farmers, include sludge analysis results, soil analysis results and quantities of sludge applied to each field.

2.2.6   Spreading of Compost and Digestate Produced in Accordance with Quality Protocols

A number of Quality Protocols have been developed to define the end of waste criteria for specific waste streams. By complying with the Quality Protocol the material produced is no longer considered

to be a waste and therefore does not have to comply with waste legislation. The Quality Protocols relevant for applying materials to land are:

- Quality Protocol: Compost. End of waste criteria for the production and use of quality compost from source-segregated biodegradable waste (2012);

- Quality Protocol: Anaerobic digestate. End of waste criteria for the production and use of quality outputs from anaerobic digestion of source-segregated biodegradable waste (2014); and

- Quality Protocol: Poultry litter ash. End of waste criteria for the production and use of treated ash from the incineration of poultry litter, feathers and straw (as a PK fertiliser in agriculture).

Individual end of waste opinions have also been given by the EA for a number of specific materials, which can be used to treat land for agricultural benefit and/or ecological improvement.

2.3   Key Sector Guidance and Supporting Information

A number of additional guidance documents have been developed in conjunction with industry and these are listed below, with the references applicable at the time Phase 2 of the Materials to Land project (January to June 2017).

2.3.1   How to Comply With Your Landspreading Permit (EA, 2017)

Environment Agency (2017). How to comply with your landspreading permit. TGN EPR 8.01. Version 3. [Online] Available at: https://www.gov.uk/government/publications/landspreading-additional-guidance.

2.3.2   Animal By-Products

Department for Environment, Food & Rural Affairs and Animal and Plant Health Agency (2014). Guidance for the animal by-product industry. [Online] Available at: https://www.gov.uk/government/collections/guidance-for-the-animal-by-product-industry.

2.3.3   General Agricultural and Fertiliser

Department for Environment, Food & Rural Affairs (Defra) (2009, updated 2013). Protecting our water, soil and air. A Code of Good Agricultural Practice for farmers, growers and land managers. [Online] Available at: https://www.gov.uk/government/publications/protecting-our-water-soil-and-air.

Department for Environment, Food & Rural Affairs (Defra) (2010 Nutrient Management Guide (RB209)) 8th ed. June 2010, The Fertiliser Manual includes information on crop diseases, how to calculate how much fertiliser to add to the soil for each crop given different soil types, and advice on how and when to apply fertilisers.

Since preparation of this report, a new version has been published by the Agriculture and Horticulture Development Board (AHDB) available online at http://www.ahdb.org.uk/projects/RB209.aspx.

2.3.4   Nitrate Vulnerable Zones

Department for Environment, Food & Rural Affairs (Defra) (2009). Guidance for Farmers in Nitrate Vulnerable Zones. Field application of organic manures. Archived. PB12736h. April 2009. [Online] Available at: http://adlib.everysite.co.uk/adlib/defra/content.aspx?id=1QQUSGMWSS.0LF53M2SBB2VFB.

Department for Environment, Food & Rural Affairs (Defra) and Environment Agency (EA) (2017). Guidance: Storing organic manures in nitrate vulnerable zones. [Online] Available at: https://www.gov.uk/guidance/storing-organic-manures-in-nitrate-vulnerable-zones.

Department for Environment, Food & Rural Affairs and Environment Agency (2017). Guidance: Using nitrogen fertilisers in nitrate vulnerable zones. [Online] Available at: https://www.gov.uk/guidance/using-nitrogen-fertilisers-in-nitrate-vulnerable-zones.

2.3.5   Quality Protocols

Waste & Resources Action Programme (WRAP) and BSi (2010). PAS 110:2010.Specification for whole digestate, separated liquor and separated fibre derived from the anaerobic digestion of source-segregated biodegradable materials. February 2010. BSi [Online] Available from: http://www.wrap.org.uk/content/bsi-pas-110-producing-quality-anaerobic-digestate.

Waste & Resources Action Programme (WRAP) and BSi (2011). PAS 100:2011. Specification for composted materials. January 2011. BSi [Online] Available from: http://www.wrap.org.uk/content/bsi-pas-100-producing-quality-compost.

Waste & Resources Action Programme (WRAP) and Environment Agency (EA) (2012). Quality Protocol. Poultry Litter Ash. July 2012. [Online] Available at: https://www.gov.uk/government/publications/quality-protocol-poultry-litter-ash.

2.3.6   Sewage Sludge

ADAS, BRC and Water UK (2001). Guidelines for the application of sewage sludge to industrial crops. April 2001. [Online] Available at: http://adlib.everysite.co.uk/resources/000/094/763/ASSIC.pdf.

ADAS, BRC and Water UK (2001). The Safe Sludge Matrix. 3rd Edition. April 2001. [Online] Available at: http://adlib.everysite.co.uk/resources/000/094/727/SSMatrix.pdf.

ADAS, Water UK and Bangor University (2014). Biosolids Nutrient Management Matrix. January 2014. [Online] Available at: http://www.adas.uk/Downloads/Biosolids_Nutrient_Management_Matrix.pdf.

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3.   Review of Previous Work

3.1   Introduction and Background

The M2L project is one piece of the larger programme of investigation of the potential risks associated with wastes conducted under the overarching Waste Enforcement Program (WEP). In addition to M2L, the WEP has also funded projects covering:

·   Biowaste Treatment; and,

·   Waste Sampling at Landfills and Deposit for Recovery (Dfr) sites.

This section provides a summary of the results of the WEP projects. In addition, this section reviews the findings of the Chemical Investigations Programme (CIP), which has been carried out by the UK water industry.

3.2   Materials to Land Phase 1

3.2.1   Project Description

Phase 1 of the Materials to Land project (M2L1) was developed by the EA to assess potential issues associated with the spreading of wastes to land in England, where such wastes provide a benefit (a reduced need for fertilisers or to improve soil conditions)[1]. The project developed evidence to support proposals to DEFRA to improve specific waste regulation in the areas of waste exemptions, waste to land, controls of hazardous waste entering bio-treatment processes and misclassified wastes entering landfill or waste treatment processes.

In M2L1, AECOM carried out 59 visits to sites, including 54 farms, 3 deposit for recovery (DfR) sites, a gypsum stockpile and a site where spreading of inappropriate wastes had occurred. A total of 167 soil samples, 57 solid (stackable) wastes samples and 40 liquid (non-stackable) waste samples were collected. These were analysed for an extensive suite of chemicals, including nutrients, metals, PTEs, pesticides, and other organic pollutants including PAHs, dioxins and furans and PCBs.

Where available, the deployment forms were reviewed prior to completing the site visits to identify the likely wastes, which could be on site, the type of storage facilities, the receiving fields and the benefitting crops.

Following completion of each site visit, a factual report was prepared detailing the results of the questionnaires, inspections and walkovers, waste sampling and soil sampling.

In addition to a factual report for each site visit, an interpretative report was also produced for 56 of the 59 sites visited. The interpretative report included as assessment of the levels of nutrient and PTEs added to the soil, which was completed by entering the site data for the waste analysis and receiving soils into the Smart Form (previously referred to as the Decision Support Tool). This is a new Excel workbook-based tool developed by the EA to allow its permitting officers to check the information provided in the agricultural benefit statement, and identify whether the levels of contaminants in the waste may pose a risk to human health, ecological receptors or controlled waters.

Due to an absence of sufficient supporting information, no interpretative reports were prepared for the deposit for recovery (DfR) sites.

In addition to the 59 site visits completed, a separate set of deployments was selected for desk-based assessment. A total of 48 desk studies were reviewed.

A separate set of 24 deployments were selected for detailed assessment of risks to groundwater in nitrate SGZs. The risk from nitrate leaching was assessed for each selected deployment through the use of MANNER-NPK.

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[1] AECOM Infrastructure & Environment Limited, Phase 1 Report - Materials to Land – Technical Summary Report. November 2016, Ref: 60473975 / TECH2

3.2.2   Key Findings

3.2.2.1   Deployment Applications / Agricultural Benefit Statements

Approximately 92 of the 107 combined site visits and desk-based assessments had potential issues identified with agricultural benefit statements and / or deployment applications, which corresponded to approximately 86% of the total deployments reviewed.

Along with the original deployments, the EA also provided copies of follow up correspondence between the National Permitting Service (NPS) and the applicants. The large number of deployments with additional correspondence between the NPS and applicants suggests that, for the most part, the NPS were managing to identify deployments where crucial information is missing.

In some cases, the missing information did not materially affect approval of the deployment (e.g. lack of qualifications for Nominated Competent Persons [NCP]). However, in other cases, the data gaps and discrepancies were material and resulted in a long trail of correspondence between the applicant and the EA permitting staff over missing analytical data, changes to the proposed wastes, need for completion of a more robust risk assessment, and clarification over waste volumes and storage etc.

In many examples, the final deployments authorised by the NPS were substantially different (e.g. with different wastes or receiving fields) from the original application, which made auditing of the deployments and tracing the individual waste streams by the local EA Area teams more complicated.

3.2.2.2   Benefitting Crops

During seven of the 59 site visits (12%), different benefitting crops were identified in the receiving fields compared with those listed in the deployment. In most instances, this change appeared to be due to administrative oversight or a change in the cropping rotation and accompanying Nutrient Management Plan. For other sites, the proposed spreading did not occur, and the farmer was forced to amend the cropping or leave the fields bare.

In one example, the crop was seeded later than originally proposed (e.g. winter wheat was amended to spring barley). If the spreading had taken place prior to the closed periods (and proposed seeding of the winter wheat), the absence of crop cover over the winter months may have allowed increased leaching of nutrients from the soil.

In other cases, the change in cropping occurred after spreading and effectively meant that the agricultural benefit statement for the spreading no longer applied. If the new benefitting crop (e.g. maize or mustard seed) had lower nutrient requirements than the benefitting crop used for the agricultural benefit statement (e.g. winter wheat), then the receiving soil had received more nutrient required by the crop, increasing the risk of leaching of nutrients. It was unclear whether changes to the previously proposed cropping rotation were due to genuine external factors such as weather, or whether this reflected a more deliberate strategy to select the worst case crop with the highest nutrient demand to justify maximising the amount of waste which could be spread.

3.2.2.3   Waste Type / Mis-description

As part of the desk based deployment assessment, AECOM conducted a simple internet search on all of the waste producers listed in each desk based assessment deployment to assess their main area of operation. From this initial assessment of the desk-based deployments, no unusual waste producers were identified, though it is noted that several of the producers had multiple components to their business, some of which may have included handling and disposal of hazardous wastes.

Only a few examples of waste mis-description were identified from either site visits, or desk-based assessments for SR2010 No.4 deployments. Generally, ambiguity or uncertainty about the potential waste code used for a particular waste stream were noted during the deployment review process and queried by the NPS.

An example of mis-description of wastes was identified for non-deployment spreading, not subject to permitting requirements, where sewage screenings were wrongly classified as sewage sludge and

spread to land under SUiAR. During a subsequent inspection during spreading, the local EA Area officer identified that the waste being spread should have been classified as 19 08 01 (screenings), and was not authorised to be spread to land.

EA local area staff suggested that the incidence of mis-description of waste may be much higher for quality protocol wastes and materials spread under exemptions than for wastes covered under deployments, and included:

· spreading of composts under PAS100 quality protocols which didn't meet the specification; and

· spreading of cess wastes under SUiAR.

3.2.2.4   Potential Over-Application of Nutrients

Of the 107 combined site visits and desk-based assessments, potential over-application of nutrients was identified in 100 cases. Many of these instances were based on the theoretical over-application of at least one nutrient (typically P, K, Mg or S) from the output of the Smart Form. In the majority of instances, the potential over-application was because operators may only have considered levels of an individual nutrient conferring benefit when assessing spreading rates, with the result that the enrichment of lesser nutrients was not necessarily assessed. While the Smart Form will identify these instances as over-application, it is down to professional judgement for each individual case as to whether this constitutes actual over-application.

Equally, the initial version of the Smart Form used for the M2L1 assessment did not take into account potential crop offtake. The updated version of the Smart Form includes an assessment of potential offtake of P and K by crop offtake.

Further evidence of over application included:

· analytical results for the wastes sampled during the project indicating higher nutrient levels than presented in the lab analysis accompanying the deployment application;

· evidence of reduced crop yields during the site audits, which the farmer attributed to result from an imbalance in relative nutrient levels; and

· identification of high nutrient wastes being spread to land, where this could not be justified based on the identified levels of nutrient in the receiving soils and the type of benefitting crop.

3.2.2.5   Mixed Wastes

Potential issues associated with mixed wastes were identified for 39 of the 107 deployments reviewed during the site visits and desk-based deployments (equating to approximately 36%). Results from the mixed wastes sampled and analysed were in some cases vastly different from the composition presented in the deployment.

Striping of crops was identified during several site visits, and in one case was attributed by the farmer to differences in the waste spread. Because of the time of year when visits were conducted (typically following harvest of mature crops and after planting of winter crops), and because striping was not readily identifiable in juvenile crops, striping may be more common than the site visits would suggest. The consultation responses from some of the EA officers also identified striping as an issue in their Area.

Finally, anecdotal evidence from EA Area staff indicated that operators may be using the mixed waste approach to mask disposal of individual high risk waste streams not suitable for land spreading without treatment.

3.2.2.6   Waste Storage

There were examples of deployments being used to allow "temporary" storage of wastes at farms, as a way of avoiding installation of additional storage facilities (e.g. at the place of production, or an intermediary storage site).

In other examples, the waste storage facilities (most notably lagoons) allowed storage of much more waste than authorised under a single deployment, raising questions about how well the batches of waste spread on individual fields were controlled.

Other storage issues identified during the project included:

·   poor condition of waste storage tanks and lagoons which didn't comply with the Storing Silage, Slurry and Agricultural Fuel Oil (SSSAFO) guidance;

·   evidence of leaking tanks and lagoons;

·   waste stored in a different location than identified in the deployment application; and

·   inappropriate location of waste (primarily for stackable waste stockpiles) in relation to sensitive receptors or public access.

3.2.2.7   Timing of Waste Applications

The relative timing of the waste application was identified as a potential issue for 70 of the 107 deployments reviewed. The biggest concern was confusion over the start of spreading, which could occur any time within the 12 months of authorisation of the deployment, excepting any applicable closed periods. This uncertainty in spreading was recognised as a particular problem for the EA when trying to arrange site visits to audit the waste spreading.

While multiple deployments for a single receiving crop may be justifiable on the basis of the nutrients supplied, there were examples where the agricultural benefit statements didn't always consider the nutrients applied by the other deployment, resulting in nutrients being applied at levels exceeding those required for agricultural benefit. In some instances, this was because the farmer had not informed the individual operators that another waste was being spread on the same fields within the same crop rotation. The use of multiple deployments for individual fields also made auditing of the spreading more difficult.

In other cases, spreading was delayed, and the wastes were stored over the winter at the farm (or in the field) resulting in an increased risk of;

·   leaching of nutrients;

·   windblown erosion of the stockpile; and

·   exposure to human and environmental receptors.

3.2.2.8   Receiving Fields

A number of potential issues were identified associated with receiving fields:

·   the area available for spreading in a field was smaller than provided in the deployment, due to changes to the field boundary, incorporation of no-spread buffers and presence of boundary crops;

·   evidence of spreading in no-spread buffers;

·   wastes spread to different fields than listed in the deployment;

·   identification of physical contaminants within the fields after spreading;

·   poor incorporation of wastes into receiving soils; and

·   drainage issues.

The most significant issue was the potential build-up of physical contaminants in receiving soils, which was recognised as potentially resulting in soils becoming unsuitable for agriculture.

3.2.2.9   Potential Contaminants in Waste

An assessment of the relative risks to the soils from additions of metals, PTEs and PAHs in wastes was made using the Smart Form, and the results did not generally indicate enrichment due to the individual spreading events considered. However, it is recognised that the background concentrations of metals, PTEs and PAHs in receiving soils may already reflect inputs from previous spreading events and that low levels of enrichment identified from a single spreading event may not be sufficient to confirm that enrichment is not occurring over the longer term as a result of repeated applications of wastes.

For stackable (solid) wastes the most common individual contaminant identified was Bis(Ethylhexyl)phthalate (DEHP), commonly found in plasticisers, which could be indicative of elevated concentrations of plastic particles within the waste stream. Contaminants present within stackable wastes also included pesticides (particularly glyphosate and aminomethylphosphoric acid (AMPA), a breakdown product of glyphosate), and PCBs (Congeners 105 and 118).

For non-stackable (liquid) wastes, in addition to glyphosate, AMPA and PCBs, additional contaminants included phenol, methylphenol and toluene, common volatile organic compounds (VOCs) associated with the use of solvents and present in some cleaning agents.

3.2.2.10   Contamination of Soils

The concentrations of contaminants including metals, PAHs and dioxins and furans detected in soils were broadly consistent with concentration ranges identified in the UK soil and herbage pollutant survey (SHS)[2], and additionally for metals background soil concentrations identified by British Geological Survey (BGS) data, with the following exceptions:

·   highest concentrations of metals detected were typically associated with soils sampled at deposit for recovery (DfR) sites;

·   concentrations of copper, molybdenum, selenium and zinc exceeded PTE limits and background soil concentrations; and

·   maximum concentrations for six of the 17 PAHs analysed exceeded the maximum concentrations identified in the SHS at least once.

More unusual organic contaminants were identified in soils, but the range of compounds differed from those detected in stackable and non-stackable wastes. The detections were dominated by the pesticide glyphosate and AMPA, a breakdown product of glyphosate, possibly not from the wastes but due to the widespread use of glyphosate as a pesticide.

The presence of PCB-like dioxins (congener 105 and congener 118) was consistent with the detection of these compounds in non-stackable waste samples, and likely reflected the ubiquitous presence of these chemicals in the environment.

3.2.2.11   Nitrate Vulnerable Zones

The relative timing of spreading of wastes and in particular high readily available nitrogen (RAN)-wastes (e.g. blood and food processing effluents and sludges) can have a significant impact on the subsequent availability of nitrogen (N) to the crop, and the potential for leaching of nitrates from soils. Nitrate leaching from soils is of major concern in areas designated as nitrate vulnerable zones (NVZ).

To limit the risks of leaching, a ban on the spreading of high N wastes during the closed period (typically between October and January) was imposed in NVZ Areas. The basis for the closed period is that between the months of October and January, the following conditions are present:

·   the plant requirement for N and other nutrients is very low;

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[2] UK Soil and Herbage Survey, Environment Agency (June 2007)

- low temperatures limit the activity of soil bacteria, with less nitrate being converted into less available forms; and

- high rainfall maximises the potential for runoff and leaching to groundwater.

Experience from M2L1 has identified the following potential issues:

- spreading taking place during the closed period;

- spreading of non-stackable wastes on soils immediately following harvest of the previous crop in late September, with the next crop not scheduled for planting until the spring (see waste storage comments in Section 3.2.2.6); and

- spreading of high available N wastes during the dry summer months can lead to mineralisation of the N which can subsequently be prone to mobilisation and leaching through the following winter.

3.2.2.12 Environmental Risks

In terms of environmental risks, a number of areas of concern were identified, including:

- spreading of wastes in close proximity to receptors including residential properties, surface water receptors, nature reserves and other ecological receptors;

- failure to employ an adequate buffer zone during spreading activities, and potentially allowing wastes to enter surface drains adjacent to the fields;

- leaks and surface runoff from wastes being stored incorrectly (e.g. overflowing lagoons); and

- introduction of persistent contaminants at low levels which over repeated applications can accumulate in soils to levels which may bioaccumulate in crops and pass into the human food chain;

- introduction of physical contaminants (e.g. plastics) which impact the continued viability of the receiving soils to support crop growth.

3.3   Deposit for Recovery

In addition to M2L1, the WEP has included projects covering Sampling Wastes at Landfills and Deposit for Recovery (DfR) sites, plus Biowaste Treatment (discussed in Section 3.4 and Section 3.5). The waste sampling project investigated the composition of waste accepted at a selection of landfills for inert waste and DfR sites, to assess compliance with permit conditions and establish the environmental risk posed.

Under WEP Project 7, the EA visited and sampled waste from 17 sites: 11 of these were Deposit for Recovery (DfR) sites, and the remaining six were inert landfills.

The specific operations for which DfR was permitted at these 11 sites were:

- landfill restoration (two sites);

- golf course construction (two sites);

- quarry restoration to agriculture (two sites);

- restoration of dredging lagoons;

- woodland creation;

- bund construction at a shooting club;

- creation of fishing lakes; and

- equestrian centre construction.

3.3.1   Exceedance of Inert Waste Acceptance Criteria

Samples of waste were collected for analysis from each DfR site (with a total of 91 samples taken). An additional 69 samples were collected from the six inert landfill sites, giving a total of 160 waste samples collected from 17 sites. Samples were analysed for the chemicals specified in the Inert Waste Acceptance Criteria (WAC), using a leachate test. Samples were also analysed for the presence of asbestos fibres, and inspected for the presence of gypsum.

The inert WAC only applies to inert waste landfills, not to DfR sites. However, the EA took the view that the inert WAC represent a benchmark for assessing whether waste is actually inert and therefore suitable for deposit to land. Key conclusions of this assessment were:

·   72% of samples breached WAC for inert landfills. While these limits only legally apply to inert waste landfills, these results give a useful indication of the pollution potential of waste used in construction, restoration and remediation under DfR permits. The results of this screening are described in more detail in Section 3.3.1.2, below;

·   sulphate and gypsum were found in excess of threshold concentrations in the majority of samples. This suggests a significant problem with gypsum waste finding its way into waste destined for landfill or DfR. The results suggest that in 10 cases there could potentially be an increased risk of generation of hydrogen sulphide;

·   33 samples had elevated organic matter, 13 had elevated levels of metals and 10 had high leachable nutrients, but further site specific assessment would be required to assess the impact of these results; and

·   two samples were suspected to be hazardous waste.

3.3.1.1   Asbestos in Waste

All samples taken under this project were screened for potential asbestos fibres as a precautionary measure for health and safety reasons. This is because the planned waste forensic analysis involved manual sorting of waste, which could release asbestos fibres. The results of this screening are summarised below:

·   screening identified that 46 out of 160 samples contained fibres, provisionally including one or more types of asbestos. The laboratory carrying out the screening[3] didn't have an in-house capability to quantify asbestos, so the 46 samples were sent for sub-contracted further analysis elsewhere;

·   the sub-contractor carried out a further screening exercise on the samples and identified that only 10 of these 46 samples (less than 6.5% of the 160 samples) contained asbestos fibres;

·   all 46 samples were passed forward for asbestos quantification using two different methods, an asbestos count and a gravimetric method that has a lower limit of detection;

·   none of the 46 samples contained asbestos at or exceeding the 0.1% hazardous waste threshold under the asbestos fibre count method. All results were below the minimum reporting value; and

·   none of the 46 samples contained asbestos at or exceeding the 0.1% hazardous waste threshold under the gravimetric method. Eight samples were found to contain fibres at a concentration above the minimum reporting value of 0.001% (the maximum detected value was 0.048%).

3.3.1.2   Waste Acceptance Criteria (WAC) for Inert Landfill Sites

The results of this screening against WAC for inert landfills were as follows:

·   a total of 148 samples were analysed for all or some of the determinands for which there are limits in the WAC for landfills for inert waste;

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[3] Analysis was carried out by the National Laboratory Service (NLS).

· 107/148 (72%) of these samples contained at least one determinand at a concentration which exceeded the limit value. However, as only part of the WAC suite was conducted in some cases, and because some limits can be used alternatively for others, definitive conclusions about compliance with inert WAC limits can only be drawn at a site level. This requires reference to Council Decision 2003/33/EC and EPR 2010 Schedule 10;

· all 17 sites sampled had at least one exceedance of WAC limits; and

· 47 of these 107 breaches were at the 5five landfills for inert waste that were sampled where the WAC constitute legal limits.

3.3.2   AECOM Assessment of Risks and Recommendations

3.3.2.1   Lack of Controls on Incoming Waste

Many samples were found to contain contamination, such that they did not correspond to the waste category and waste description identified in the permit application. As a result, an unquantifiable but likely risk included the deposition of significant volumes of mixed non-inert construction waste on land under the guise of a recovery operation.

The current procedures for waste acceptance at most of the sites are either:

· inadequate in conception; and/or

· not robustly applied in practice.

Measures identified to address this issue included:

· greater scrutiny of agreed risk assessment criteria and waste acceptance criteria during consideration as to whether to authorise or deny the permit application;

· more robust inspection procedures by the EA, including additional upstream auditing of the waste producers supplying wastes brought to site; and

· completion of a post-completion verification survey, with a requirement to carry out remedial work in the event that non-compliant waste is identified. To ensure transparency, the survey may need to be either carried out or certified by an independent organisation.

3.3.2.2   Exceedance of Inert WAC

The Inert WAC limits for leachable sulphate was exceeded in many (79 out of 148) cases; often associated with the observable presence of gypsum in the waste. Additionally, 31 out of 148 samples exceeded the Inert WAC limit for leachable antimony, while the inert WAC level for total dissolved solids (TDS) was also exceeded in 51 out of 104 samples.

These results suggest that leachable sulphate and antimony are both widely present in waste (predominantly construction waste) that is either deposited for recovery or disposed of at inert waste landfills.

Two possible opposing hypotheses can be inferred from the results, either that:

· inert WAC criteria are appropriate, and these wastes should not be considered as inert. The continued disposal and deposit of these wastes poses an environmental risk; or

· inert WAC criteria are not appropriate for screening the wastes and an additional set of more realistic and risk-based assessment criteria should be developed which specifically address potential leachate risks from deposition of the wastes such that the continued disposal and deposit of these wastes can be better assessed.

In order to determine which of these hypotheses is correct, it will be necessary to carry out an environmental, health and safety risk assessment for leachable sulphate and leachable antimony.

3.3.2.3   Presence of Asbestos

Many samples (46 out of 160) were identified to contain asbestos fibres following an initial screening, with eight of the 46 samples containing asbestos above the minimum reporting value of 0.001% based on gravimetric analysis. The results show that asbestos fibres are present in a significant proportion of the samples of material deposited to land.

There are a number of different pieces of legislation and guidance relating to asbestos in wastes and soils in the UK and some of the most salient points are summarised below:

- there is no current acceptability threshold for asbestos in soils in the UK;

- there are two independent criteria for determination of wastes as hazardous, with respect to asbestos (Guidance on the classification and assessment of waste (1st edition 2015) Technical Guidance WM3, Environment Agency):

    – if the waste contains fibres that are free and dispersed then the waste will be hazardous if the waste as a whole contains 0.1% w/w or more asbestos; and

    – if the waste contains any identifiable pieces of suspected asbestos containing material. The waste is hazardous if the concentration of asbestos in the piece of asbestos containing material is 0.1% w/w or more;

- under EU Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation, "the manufacture, placing on the market and use of these fibres and of articles and mixtures containing these fibres added intentionally is prohibited";(Annex XVII - Conditions of restriction, European Chemicals Agency, https://echa.europa.eu/documents/10162/574c30dd-398d-b3ff-cc67-e7e843c2b243);

- the transportation of asbestos containing materials will be subject to the Carriage of Dangerous Goods Act (2009) "*waste containing asbestos must be consigned under the relevant waste rules which include a "duty of care". That duty of care means, amongst other things, that duty holders prevent escape of the waste whilst it is in their control. All movements must be accompanied by a hazardous/special waste consignment note.*" For transportation of waste rubble or soil contaminated with asbestos, the following rules apply "*Certified packaging (available in up to 2 tonnes capacity bags) within skip or freight container. Bulk transport not allowed*";

- any work with or work liable to disturb wastes containing more than trace amounts of asbestos are subject to the Control of Asbestos Regulations (CAR) 2012;

- Article 14 of the Waste Framework Directive requires the necessary measures to be taken to ensure that waste is recovered or disposed of without endangering human health and without using processes or methods which could harm the environment, including:

    – without risk to water, air, soil or to plants and animals;

    – without adversely affecting the countryside or places of special interest; and

- the CL:AIRE Definition of Waste Development Industry Code of Practice (2011) restricts the use of material from one site (donor) to another (receiver) to material that:

    – does not increase hazards to human health or the environment beyond those which already exist at the site by importing materials with contaminant levels higher than those already present; and

    – to material that does not introduce new hazards by importing material that contains new contaminants at problematic concentrations.

Additional guidance is required by the EA and operators to assess whether the presence of low but measureable concentrations of asbestos fibres are sufficient to "increase the risk associated with the waste sufficiently to justify their disposal in other classes of landfill", or to prevent their deposit to land for recovery.

Considering the possible end uses for DfR sites, the presence of asbestos may still result in increased risks to human health, due to the increased risks of exposure associated with:

- transportation and placement of the wastes; and

- future disturbance of the soils during ploughing, harvesting and future applications of fertilisers / waste.

It is recommended that all of above be considered carefully in developing comprehensive guidance to clarify whether wastes containing asbestos are suitable for spreading to land at deposit for recovery sites.

3.4 Inappropriate Waste Entering Biowaste Treatment

3.4.1 Project Description

The EA developed a "Framework for Assessing Suitability of Wastes Going to Anaerobic Digestion, Composting and Biological Treatment" (referred to as the "Jacobs Framework) in 2012 to reduce risks of inhibition of biological processes and resulting in material not suitable for agriculture. Potentially problematic wastes include particular industrial liquid wastes.

The aim of this project was to understand how well the Framework has been adopted; and to review and further characterise wastes added to standard rules permits/quality protocols, particularly to confirm waste is correctly described.

This project comprised four strands:

3.4.1.1 Strand 1 – Waste Types

A Rapid Evidence Assessment (REA) methodology was used to evaluate the risks associated with wastes from four key sectors. This strand is discussed in more detail in Section 3.5, below.

3.4.1.2 Strand 2 – Waste Producers

Twenty three (23) waste producers were audited, focussing on production of liquid waste not containing hazardous substances (EWC 16 10 02). Three of these facilities were not required to have a permit, with the remaining twenty permitted under EPR. A total of 35 waste samples were collected for analysis from 31 waste streams at 19 sites, with 27 samples were analysed.

3.4.1.3 Strand 3 – Biowaste Treatment Sites

Twenty (20) biowaste sites were audited, with a focus on poor performers or those receiving liquid wastes not containing hazardous substances (EWC 16 10 02). A total of 23 waste samples were collected for analysis from 16 separate facilities.

3.4.1.4 Strand 4 – Sewage Treatment Works Desktop Audits

Under the former Waste Management Licensing regulations, liquid waste delivered to WwTW by tanker required a licence, but under EPR, this is no longer required since "deposit" of liquid waste is not an R or D code activity under Waste Framework Directive. However, a permit is required by the WwTW under EPR for co-digestion of waste and sewage.

The results from Strand 2 showed multiple waste streams were being sent to WwTW, with potential risks to the status of the resulting sludge. Desk-top reviews were therefore carried out for a number of large water companies, covering the types of waste accepted, potential for mis-description, and extent of producer audits carried out.

3.4.2 Key Findings

3.4.2.1 Strand 1 – Waste Types

The results of this strand are summarised separately in Section 3.5 "Rapid Evidence Assessment (REA) for Specific Sectors".

3.4.2.2　Strand 2 – Waste Producers

The following paragraphs summarise the findings and recommendations reported by the Environment Agency under Strand 2.

Various permit breaches were identified, including:

· miscoding of waste;

· inadequate transfer/consignment notes; and

· use of unauthorised sites in three cases; and difficulties in tracing waste movements.

Nine waste streams were miscoded – most commonly EWC 16 10 02 (aqueous liquid wastes other than those mentioned in 16 10 01) was used to describe waste that was likely to be hazardous. Seven of these waste streams originated from chemical/cosmetic manufacturers.

Of the samples analysed, all demonstrated some degree of inhibition to biological processes (when compared to the criteria in the Jacobs Framework), with 15 samples having characteristics making them unavailable for biological breakdown. Other issues included presence of pesticides, high conductivity, and presence of lubricating oil compounds.

21 of the 31 waste streams previously sent for composting/AD, were now being diverted to sewage works. The Framework for assessing bespoke waste streams appears to have positively impacted the compost sector. Over half the sites audited had sent waste to compost sites in the past and had ceased to do so. Almost half of the sites audited had heard of, or were using the Framework for assessing waste.

It was not always possible to track waste sent directly from on-site effluent treatment plants to land spreading. On occasions this waste appeared to have been spread illegally. Most waste streams demonstrated an element of inhibition or elements within the waste analysis that may be of greater concern over long term land application. However, the impact assessment was unable to be undertaken during this project.

Waste historically identified as being of 'concern' (in particular liquid effluents) were being diverted in the main to sewage treatment works and some to anaerobic digestion. The drivers for this were

· compost site permit variations;

· the introduction of the framework for assessing suitability of wastes for biowaste treatment; and

· investigation of a number of compost sites.

The report noted that if this was a more widespread behaviour for liquid wastes generated at chemical/cosmetic manufacturers, there was a risk that the resulting sludge or digestate may not comply with the Sludge (Use in Agriculture) Regulations and may pose a risk to agricultural soil quality in the long term. However, the report did not include further evidence to demonstrate that this was the case.

Further findings included:

· instances of tankers moving some distance and out of the water company catchment. The reliance on Trade Effluent agreements for tankered waste may not be appropriate;

· there appeared to be a lack of parity between the waste treatment model and the water industry model; and

· failing to understand WM3 guidance appeared to be a significant issue, with respect to correctly identifying hazardous waste streams.

The report recommended:

· further investigation in assessing risk to agricultural land where effluent waste was treated at sewage works and there was the possibility that chemical contamination may carry over to the sludge;

- both producers and land spreading firms must keep accurate records of spreading activity;

- increased upstream auditing, alongside increased awareness within the chemical and industrial process regulatory teams into miscoding issues. It was recommended that this must be implemented as part of the EA's regulatory effort at permitted facilities;

- review and relaunch of the Framework for assessment of waste for those working with sewage companies and within the waste sectors;

- a more cohesive approach between internal waste and water sectors to ensure consistency of approach with waste water treatment companies; and

- full permit review of biological treatment sites taking bespoke waste.

3.4.2.3 Strand 3 – Biowaste Treatment Sites

The following paragraphs summarise the findings and recommendations reported by the Environment Agency under Strand 3.

Based on site visits and the results of analysis, the EA concluded that:

- the introduction of the framework appeared to have ensured that waste accepted at sites was suitable for biological treatment. However, due to the focus of the project on known sites, further compliance assessment was needed to ensure waste acceptance at all sites is robust. This was especially true where sites received bespoke waste streams. Further permit review may be necessary to ensure that the practice of accepting unsatisfactory waste has ceased, where the resulting outputs can be used on agricultural land;

- the presence of organic contaminants was of interest, but requires further assessment in regards to environmental impacts associated with application to agricultural land when compared with other wastes including sewage sludge. The risks to agricultural land from successive combined applications of organic contaminants in materials should be assessed. The sample group was small and no specific conclusion could be drawn at this stage without wider work;

- there was no existing requirement under PAS 100 or PAS 110 to test for PCBs, PAHs or pesticides/herbicides. Some of these substances may be persistent in the environment and it may be wise to consider inclusion of analysis for these contaminants within the BSI regime;

- PAHs can be ubiquitous in the environment but a few samples exceeded the recommended limits from the EU JRC report. PCBs were detected in many samples, and the potential sources of PCBs in samples were not readily identifiable;

- the presence of restricted or banned pesticides was also of interest. Some of the bans and restrictions were enacted relatively recently and the presence of banned pesticides may have been a result of the use of old stock or reflect substances remaining in situ in or on plant matter. However, this did not account for the presence of DDT, and the EA speculated that this may have resulted from residues on imported vegetable waste from countries outside the EU;

- one mixed restoration material audited appeared to contain levels of contamination considered unsuitable for use in land remediation;

- a food waste sample spread to land was considered acidic and could have a detriment to soil and crops in breach of land spreading guidance;

- use of leachate that demonstrated inhibition values in anaerobic treatment should be reconsidered. Additionally, compost leachate is often used for moisture application and further assessment is needed to assess whether this practice could inhibit aerobic treatment;

- three samples of PAS compliant material demonstrated high levels of trace elements. The risk to land was not assessed in the report but should be considered as part of a PAS 100 review; and

- antimony was identified in samples from compost sites: the source of this material was not clear, and it may be indicative of contamination by waste streams other than those approved.

The report authors recommended that:

- identification and further permit review of older stock permits is required;

- review of standard rules codes to ensure all waste codes are described consistently (e.g. 19 02 03);

- amendment of waste code 19 05 99 to allow accurate application of WM3 with regards leachates and liquors;

- a further risk assessment of the impact on soil quality that gives consideration to levels of PCBs, PAHs, banned pesticides and herbicides found in compost and digestate;

- consideration to widening the range of analysis for BSI PAS 100/110 in view of the detection of other organic contamination found in this project. However, a wider sample group may be required; and

- an upstream approach must be applied to waste acceptance auditing at biological treatment sites.

3.4.2.4   Strand 4 – Sewage Treatment Works Desktop Audits

The following paragraphs summarise the findings and recommendations reported by the Environment Agency under Strand 4.

There are a number of gaps in the EA's understanding of what water companies are doing with tankered industrial wastes, how they handle them and what, if any, consequences there are for the environment. These include:

- the destinations of sludge generated at sewage works accepting industrial wastes is not known. This may impact the way the SUiAR are applied to that sludge;

- the volumes and range of waste accepted by some water companies is unclear and if the status of these waste can be accurately considered under terms of trade effluent agreements. Some wastes are moved a considerable distance. This may impact water companies with regards to the acceptance of these wastes and what considerations the water companies have when deciding whether to accept a tankered waste.

Since many of the wastes from producers contain substances that are not amenable to biological treatment, these substances are likely to end up either in water or (via sludge application) soil.

The impact on final effluent may not be clearly understood as many of the discharge parameters are unlikely to screen for certain substances.

Further information on the presence of contaminants in sludge has been obtained from the CIP1, CIP2 and M2L2 projects, and is presented in Section 5, below.

The classification of sewage sludges from large urban sewage works that accept tankered wastes was questionable, and 19 08 05 may not be the most appropriate LoW / EWC code to describe these sludges. WM3 (EA, 2015) provides a framework for WwTW operators to assess whether sludge should be considered as 19 08 11* (sludges containing dangerous substances from biological treatment of industrial waste water).

After assessment using the framework, if the sludges do not meet the criteria for classification as 19 08 05, , then EWC codes19 08 11/12 would be appropriate. These codes are not currently included in the standard rules permit for landspreading of sewage sludge, and it was noted that much of the mixed sludge was destined for farmland under SUiAR.

There was inconsistency in the way AD and biogas activities are permitted across the sector. Often the digestion process and treatment of waste with sewage sludge was not included in a permit. This approach was inconsistent with the waste sector.

A number of water companies operate co-digestion plants where the feedstock included industrial effluents. These co-digestion plants did not use the Framework guidance as other biowaste facilities were required to. This was specifically an issue where the final outputs were used on agricultural land.

Some water companies were accepting tankered industrial waste under trade effluent agreements. Wastes are treated in the sewage treatment system, or mixed with indigenous sludge and treated by anaerobic digestion, compost, lime or long term storage. These treatment processes were often not consistently regulated by environmental permits as they were carried out under urban wastewater treatment regulations.

The blending of hazardous and non-hazardous effluents and waste raised the question of the status of the waste and its treatability by the works or digestion. In some cases it was not clear how the decision whether to treat the effluent in the main WwTW, or directly in the sludge digester was reached. Some water companies did have waste permits for pre-treatment. However, what constitutes treatment was not always clear.

There were some attempts at permitted control of waste inputs e.g. metal limits in certain waste codes at some sites or the use of COD loading values. However there were no limitations for other possible contaminants such as organics.

3.4.2.5   Recommendations

The recommendations from this Strand were:

· regulator clarity and consistency should be addressed across the waste and water treatment sector. Given that most waste producers audited by the EA state that they are using sewage treatment works as a disposal route, the water industry should be audited to assess how they handle industrial wastes, how this impacts on the quality of sewage sludge going to land and whether their role in waste management undermines the rest of the industry;

· EA officers require water companies operating co-digestion plants (digestion of sewage sludge and industrial wastes) to submit evidence about the suitability of wastes for biowaste treatment using the Framework guidance. The framework guidance should be reviewed to factor in the business of water treatment works to ensure consistency;

· clarity on the status of tankered waste effluents is also required. The current situation undermines the waste industry, where regulatory scrutiny is placed on waste acceptance and end use material is scrutinised where there is uncertainty as to the level of contamination in the waste;

· the acceptance of industrial effluents for treatment questions the ability of the SUiAR to administer protection of soil quality when the status of the sludge is unclear. This should be considered for review; and

· the status of sludge from mixed hazardous waste with non-hazardous waste should also be assessed and reviewed.

3.5   Rapid Evidence Assessment (REA) for Specific Sectors

3.5.1   Project Description

The Rapid Evidence Assessments (REAs) formed part of the Biowaste Treatment project under the WEP (as described in Section 3.4.1) and formed part of the overall investigation of the biological, chemical and physical hazards presented by specific waste streams to biological waste treatment sites and the hazards associated with the application of the treated material to agricultural land. The REAs were carried out for wastes from four industries:

· wool scouring;

· biodiesel production;

· leather and fur production; and

· printing ink manufacture and formulation.

An REA provides an overview of the volume and types of evidence and knowledge available to address the primary question or topic. It is supported by a framework of more detailed or secondary

questions that provide structure to the evidence review and build-up the information that surrounds the main question. An REA sets out a comprehensive search, which aims to be thorough and transparent under identified constraints. This is accompanied by a critical evaluation of evidence, using a formal weighting system. Evidence and uncertainty is clearly documented.

3.5.2   Key Findings

The only wastes from these industries reported to be spread directly to land were wastewater treatment works (WwTW) sludge and dust from the wool scouring sector. This sector was small in the UK, with only two significant operators, both in West Yorkshire.

Although some of the wastes from each industry were potential feedstocks for composting and anaerobic digestate (AD) facilities, under the applicable Quality Protocols, the information about the extent to which this actually occurs was inconclusive.

The potential hazards associated with waste from each industry were evaluated. In the draft report "Inappropriate wastes entering biowaste treatment facilities", the same recommendation was made for each of these industries, namely that *"as insufficient data has been found during literature reviews and producer surveys to satisfy us that this waste is suitable for biowaste treatment we recommend review of quality protocols and standard rules permits. Any future waste to land spreading review should take this information into consideration. Waste producers should provide us with the necessary evidence."*

Although this conclusion was repeated for each industry studied, the actual risks vary and are discussed in more details in the conclusions of the individual REA reports.

3.5.2.1   Biodiesel

For biodiesel washings, evidence was found that pH, methanol and electrical conductivity could exceed optimum parameters for biotreatment, but no evidence of the presence of persistent, bioaccumulative or emerging contaminants, or elevated concentrations of toxic metals was presented. The main constituents of the waste were amenable to biological treatment. There were issues in the sector around whether certain outputs were classified as waste or not, and whether or not wastes from the sector were acceptable at AD facilities receiving Renewable Obligation Certificates (ROCs) or claiming the feed in tariffs (FiT); but leaving aside these regulatory issues, there was no evidence in the REA of significant risk to human health or the wider environment from application of these wastes to land.

The REA concluded that whilst the outputs from biodiesel production were generally considered suitable for biotreatment, this was based on previously-published literature and scant data from the biodiesel sector itself. The EA therefore recommended that a targeted sampling and analysis programme takes place to collate a comprehensive hazard dataset for wastes arising during biodiesel manufacture in England and Wales.

3.5.2.2   Wool Scouring

For wool scouring wastes, evidence was found that persistent and bioaccumulative contaminants could be present in the waste, particularly pesticides used in sheep dip. Since fleeces are imported for scouring from outside the EU, it was reasonable for this to include substances that are banned in the EU.

As part of their monitoring requirements under their Environment Permit, operators routinely test sludges and dust for a suite of contaminants which includes those pesticides of concern. The results showed that these pesticides were detected in some samples, although not at levels which caused the wastes to be classified as hazardous under WM3 (EA, 2015).

No evidence of risks to livestock from the application of sludge and dust to agricultural land were identified during the literature review.

Sludge and dust are not routinely tested by wool scouring operators for contaminants which are considered to be toxic to human health or endocrine disrupting. Potential hazards and risks associated with the release of fugitive dusts can be mitigated against through adoption of good practice and permit conditions.

Some of the process chemicals used in the wool scouring and wastewater treatment process and pesticides used in sheep husbandry are not readily degradable and may bioaccumulate.

Data from a UK landspreading operator shows that sludge and dust have a high biological oxygen demand (BOD) which could cause serious effects if wastes enter surface waters via run-off or via land drainage.

Cypermethrin and diazinon found in sludge and dust are on the list of hazardous substances defined by the Joint Agencies Groundwater Directive Advisory Group and are high priority veterinary medicines in terms of potential risk to UK ecosystems.

3.5.2.3   Leather and Fur

This REA was adversely affected by the industry withdrawing cooperation with the study, and no evidence was available on whether waste from this industry is actually sent for biowaste treatment or is spread to land.

Of the waste streams evaluated, only fleshings (EWC 04 01 01), were considered to be suitable for treatment, although this was likely to require the adoption of management / control measures for odour and possible off gases, which may make such waste commercially unviable e.g. requirement for enclosure and abatement.

No information was available on whether leather waste was actually sent for biological treatment or spread to land in the UK.

The review found a wide range of chemical contaminants that may be present in tannery wastes that pose a potential risk to soil, livestock/ecology, crops and controlled waters, including chromium (from chromium tanning processes) as well as biocides and veterinary medicines.

3.5.2.4   Printing Ink Manufacture and Formulation

There was limited information in the literature on biological treatment of printing ink manufacture wastes as these were typically disposed to landfill or by incineration. One UK manufacturer indicated that liquid wastes were sent for bio-treatment in the past but not currently due to higher costs of this disposal route. The limited information available indicated that the presence of trace elements and the poor degradability of some organic pollutants such as biocides would inhibit potential aerobic and anaerobic biowaste treatment.

3.5.2.5   General Conclusions and Recommendations

Based on the four REA studies carried out, the EA concluded that:

· waste streams were often complex mixtures of raw materials and process chemicals, which resulted in wide variations in potential hazards within a single waste code. Many raw inputs may appear in waste streams and may not be adequately screened;

· there was limited data to support the assumption that the identified waste streams were fully suitable for biowaste treatment and/or land spreading. The industries appear reluctant to provide any data;

· working with upstream producers was critical to better understanding the biological, chemical and physical composition of these waste streams, but obtaining this cooperation can require significant time and effort. This cannot be emphasised enough in the REA guidance and the degree of cooperation found across the four waste streams was highly variable; and

- in many cases, waste producers held little characterisation data on the waste streams generated, passing the responsibility of determining their suitability for treatment and landspreading to the biowaste treatment operator. The Framework provided a useful tool to help operators to undertake suitable assessments on a case-by-case basis.

The addition of a guide to collecting and reviewing data, so that operators more clearly understand the evidence needed to undertake an assessment.

The EA recommended that:

- consideration should be given to reviewing these wastes in Standard Rules permits for composting, anaerobic digestion and land spreading and quality protocols until operators can provide suitable evidence with regards the risk; and

- the Framework document could be improved by inclusion of further generic advice on the treatability of materials, the degradability of specific contaminants, and the potential for impact of inhibitory substances. This would be useful for both waste producers and permit holders to be able to screen waste streams, and to identify where further characterisation was required.

Although only four industries were specifically addressed using the REA process, the results were consistent and likely to be replicated across other industries, where there was a lack of comprehensive characterisation data for the wastes generated.

3.6   Chemical Investigation Programs (CIP1 and 2)

The Chemical Investigations Programme (CIP) was developed by the UK Water Industry Research (UKWIR) in response to emerging legislation on surface water quality (UKWIR, 2014). It aimed to provide a better understanding of the occurrence, behaviour and management of trace contaminants in wastewater treatment processes and associated effluents. Two phases of work have been completed, CIP1 and CIP2. Specific aspects of the CIP relating to sludge produced at WwTW, and relevant to landspreading, are discussed below.

3.6.1   CIP1 Sludge Analysis

The CIP1 investigation did not look at sludge in the sludge treatment process but rather sludge from different stages of the sewage treatment process. Assessments of sludge quality were made, as part of the wider CIP process investigations, at 28 wastewater treatment works (WwTW) sites. The following summary of the findings of the CIP1 sludge investigations is taken from a published paper by Jones et al[4].

WwTWs for were selected to be representative of different process types applied across UK sites. 14 biological-filter (BF) WwTWs, 12 activated sludge process (ASP) WwTWs, one biological nutrient removal (BNR) WwTW and one membrane bio-reactor (MBR) WwTW were included in the study. Sludge samples were collected at the participating works over a period of approximately 12 months, with 7–15 sampling occasions at each site. Sludge samples were collected at one selected point per WwTW. Samples consisted of primary sludge (collected from the primary settlement tank), secondary/biological sludge (e.g. humus sludge) or mixed sludge (mixture of primary and secondary/biological sludge) and were analysed for suites of substances including:

- nutrients;

- metals;

- emerging and regulated organics,

- polybrominated diphenyl ethers (PBDEs); and

- pharmaceuticals.

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[4] Vera Jones, Mike Gardner, Brian Ellor, Concentrations of trace substances in sewage sludge from 28 wastewater treatment works in the UK, Chemosphere, Volume 111, 2014, Pages 478-484.

Sludge samples were divided into three groups: those collected at a primary sludge, secondary/biological sludge or mixed sludge sampling point. Visual analysis of data graphs was then undertaken, and, where this suggested noticeable differences between sludge sample groups, it was followed by single-factor analysis of variance. For the majority of trace substances, the CIP1 researchers found no major differences in concentrations between the three different sludge types sampled. There were some exceptions to this observation. Triclosan, propanolol, ibuprofen, erythromycin and nonylphenol concentrations differed to a marked extent between the three sludge groups ($p < 0.05$), with levels being generally higher in the primary and mixed sludge samples than in the secondary/biological samples. The CIP1 researchers examined the relative hydrophobicity of these substances (using log k_{ow} as an indicator of hydrophobicity). This analysis suggested that log k_{ow} is not a good indicator for the presence of trace substances in different types of sludge, which is likely to be affected more significantly by mechanisms such as biodegradation.

Sludge data were then divided into two broad groups to determine whether trace substance concentrations varied significantly between different types of WwTW: those collected at WwTWs operating BF and those employing ASP. The BNR and MBR WwTWs were not included in this analysis, as they represented single data points). The results only suggested significant differences in concentrations between ASP and BF plants for bromo diphenyl ether (BDE) 47, with BDE 47 concentrations being higher in sludge collected at BF plants compared to those collected at ASP plants. Results for all other parameters did not show any significant difference between ASP and BF plants, suggesting that the type of treatment process employed at different WwTWs does not have an overall significant effect on the concentrations of trace chemicals in sludge.

The relationship between median fractional removal (influent to effluent) at each WwTWs and each substance, and median concentration in sludge, was examined by regression analysis. The aim was to assess whether, for any of the chemicals considered, works with higher influent to effluent removal also exhibited higher concentrations in sludge. The results of this analysis did not indicate any statistically significant relationships between fractional removals and concentration in sludge for any of the substances considered.

The relationship between influent/effluent concentration and concentration in sludge was also investigated by means of regression. Mean sludge concentrations were plotted against mean influent and then effluent concentrations for each WwTW. This indicated the presence of a potential link between these two variables for three metals only (copper, lead and nickel), although the relationship was not statistically significant. For all other determinands, levels in the influent or effluent did not appear to be related in any statistically discernible way to concentrations in sludge. The CIP1 researchers noted that metals are the most conservative of the trace substances considered in this study, and it was, therefore, not surprising that there was a link between influent/effluent and sludge concentrations for these determinands as they are not significantly affected by degradation processes during the transfer of a substance from wastewater to sludge.

The CIP1 researchers assessed results between the WwTWs by comparing the coefficient of variation (CoV) for influent and effluent concentrations to the CoV for sludge concentrations for each substance. This comparison indicated that the CoV (and hence between-works variability) was greater in influent concentrations than in sludge concentrations for 25 out of the 37 determinands considered in both effluent and in sludge. The same comparison for effluent indicated that the between-WwTWs CoV was higher for effluent concentrations than for sludge for 26 out of the 37 determinands considered in both effluent and in sludge.

This suggested that, although the quality of influent (and effluent discharged) is relatively variable between WwTWs, this variability is greatly decreased when it comes to sludge. The researchers noted that it was possible that this was the result of the long residence time that sludge exhibits, which means it is an overall well-mixed and highly-degraded entity. They also noted that it may also indicate that a number of factors affect sludge concentrations without one factor being the predominant control. The overall effect was concluded to be broadly consistent concentrations across the considerable number of samples analysed for the CIP1 study.

The CIP1 researchers noted the significant uncertainty on the nature and extent of the processing between the point at which samples for the CIP1 study were collected and the final digested/aged

sludge product that might be applied to land. Therefore, the researchers noted that it was not possible to assess compliance with regards to sludge concentration thresholds. Recognising this limitation, the CIP1 researchers deemed it valuable to compare the results with the current and proposed EU limits for sludge in agriculture to give an indication of the potential for the final treated sludge to comply with regulation.

- concentrations of nickel in the CIP sludge samples were below the current/proposed thresholds at all WwTWs sampled. Nickel concentrations at all works remained below the relevant threshold of 300 mg/kg;

- copper concentrations were below the threshold at all WwTWs, with the exception of a BF plant (median value of 1,134 mg/kg, against a threshold of 1,000– 1,750 mg/kg);

- concentrations of lead, zinc, cadmium and mercury were below the current/proposed thresholds at all WwTWs;

- benzo(a)pyrene concentrations at all WwTWs were below the proposed threshold of 2 mg/kg;

- concentrations of persistent organic pollutants (POPs) were also compared to the then-proposed EU POP concentration thresholds for waste[5]: PBDE 47 and the sum of PBDE 100 and PBDE 99 were significantly lower (5 orders of magnitude) than the proposed POP thresholds at all works;

- an assessment of levels against soil predicted no-effect concentrations (PNEC) was also undertaken by the CIP1 researchers. Soil concentrations were estimated based on an application of 7 tonnes of dry sludge per hectare of land and 3,254 tonnes of soil per hectare of land. Predicted metal soil concentrations, based on the mean concentration across all WwTWs, were at least one order of magnitude lower than the soil PNEC:

- the predicted soil concentration for BDE 99 (based on the mean across all works) was 5 orders of magnitude lower that the soil PNEC, while the predicted BDE 99 soil concentration based on the maximum value reported across all works was still 4 orders of magnitude lower than the PNEC:

- for the majority of PAHs considered, estimated soil concentrations (based on both the mean and maximum value across all works) were one to two orders of magnitude lower than the PNEC. The only exception was the concentration of benzo(a)pyrene which was slightly higher, but still 1 order of magnitude lower than the soil PNEC:

- the estimated soil concentration for nonylphenol (based on both the minimum and maximum value) was one order of magnitude lower than the relevant PNEC:

- soil PNEC for pharmaceuticals do not exist, however Eriksen et al. (2009) considered a cut-off of 100 µg/kg below which pharmaceuticals levels are regarded as presenting negligible environmental risk by the European Medicines Agency (EMEA). Exceptions to this are higher risk pharmaceuticals, such as anticancer drugs and hormones, for which a cut-off of 10 µg/kg is considered applicable: and,

- the estimated soil concentrations for pharmaceuticals, applying the same ratio as above to convert sludge to soil concentrations (UKWIR, 2013), suggested soil concentrations of <1 µg/kg based on means and <10 µg/kg based on maxima for ibuprofen, propanolol, erythromycin, ofloxacin, diclofenac and fluoxetine. These values are below the Eriksen et al. (2009) threshold for pharmaceuticals, and also the threshold for higher risk drugs. Predicted concentrations of oxytetracycline were estimated at 16.3 µg/kg and 91.65 µg/kg (based on means and maxima, respectively), hence below the threshold of 100 µg/kg.

Based on the sampling and analysis they had undertaken, the CIP1 researchers concluded that the study indicated a broadly-consistent 'picture' of trace substances in sludge, such that the trace substance content of sludge may be characterised with some certainty for most substances considered in the CIP1 study, irrespectively of the sludge provenance, hence making risk assessment of its re-use more reliable.

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[5] AECOM assumes that this refers to the concentration limits defined by the EU, above which the POPs content in waste shall be subject to destruction or irreversible transformation.

A comparison of this finding with respect to the findings from the Materials to Land project is summarised and discussed in Section 5 below.

Despite the large number of substances investigated in CIP1, the researchers noted that many further determinands found in sludge have been highlighted as posing a potential risk to the environment and human health, and therefore may warrant further investigation.

3.6.2   CIP2 Sludge Analysis

The Chemical Investigations Programme Phase 2 (CIP2) Sludge Investigations built on the earlier CIP1 sludge investigations, and focused primarily on assessing trace substance concentrations at different points within the sludge treatment process[6].

Examination of sludge in its final form before reuse (e.g. in agriculture) was outside the scope of this work.

The key objectives of the CIP2 sludge investigations were to:

·   examine how the concentrations of selected trace substances varied throughout the wastewater treatment process;

·   assess trace substances concentrations in sludge cake with regards to the existing Sludge Directive (86/278/EEC) thresholds and other proposed standards; and,

·   examine trace substances predicted soil concentrations after application of sludge to land with regards to the PNECs.

The programme consisted of monitoring at 11 WwTWs at four locations per WwTW, during a period of 10 to 12 months. The aim was to collect 40 samples per works.

Sites were selected to represent a range of different wastewater/sludge treatment processes.

The sampling locations within each works were selected to align broadly with the following points: upstream of anaerobic digesters/lime treatment; downstream of anaerobic digesters/lime treatment; sludge cake downstream of dewatering; and return liquors from dewatering. The determinands considered included eight metals and 21 pharmaceuticals, as shown in Table 3-1.

Table 3-1: CIP Analytical Suite

Metals	Pharmaceuticals
Nickel total	Diclofenac
Lead total	Ibuprofen
Copper total	Atorvastatin
Zinc total	Ortho-hydroxyatorvastatin
Cadmium total	Para-hydroxyatorvastatin
Mercury total	Propranolol
Iron total	Atenolol
Chromium total	Erythromycin
	Norerythromycin
	Azithromycin
	Clarithromycin
	Ciprofloxacin
	Metformin
	Ranitidine
	Carbamazepine
	10,11-epoxycarbamazepine
	Sertraline
	Norsertraline

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[6] UK Water Industry Research Limited. CIP2 Sludge Investigations. 2017.

Metals	Pharmaceuticals
	Fluoxetine
	Tamoxifen
	Trixylenyl phosphate

Data analysis carried out by the CIP2 researchers indicated there was no clear overarching picture in the variation of trace substance concentrations throughout the wastewater/sludge treatment process. Broadly, metals concentrations at most works differed significantly between the raw sludge and sludge cake, with levels being higher in the sludge cake.

In contrast, pharmaceuticals concentrations were not shown to differ significantly between the raw sludge and sludge cake in most cases. The CIP2 researchers concluded that this may be due to the large number of results below the limit of detection (LoD) for these substances, but could also reflect the fact that pharmaceutical substances are degraded during treatment and this tends to counterbalance the process of concentration during sludge treatment.

The CIP2 researchers compared results for the sludge cake samples from each WwTW with current Sludge Directive (86/278/EEC) limit values as well as proposed revised thresholds. This analysis indicated that metal concentrations were significantly below the Directive thresholds at all works sampled and were indicative of likely compliance.

Predicted soil concentrations after application of the sludge cake to land were calculated by the CIP2 researchers, and compared against soil PNECs. It is not clear from the CIP2 Sludge report whether this considered single or multiple applications. This calculation suggested that soil concentrations would be significantly below the soil PNEC for all metals considered. Also, all pharmaceuticals predicted soil concentrations were lower than the thresholds indicative of negligible environmental risk.

The exception to this was chromium at all sites, for the hexavalent chromium (Cr VI) soil PNEC – although AECOM notes that the result for total Cr seems to have been compared to the PNEC for Cr VI. This is likely to overestimate considerably the risk, since it is unlikely that all Cr would be in the form of Cr VI.

The CIP2 researchers found that concentrations for all the pharmaceuticals considered were well below the threshold indicative of negligible environmental risk, even when applying the more stringent standard for higher risk pharmaceutical substances.

Based on the findings of the CIP2 investigations, the CIP2 team made the following recommendations with regard to future work on trace substances in sludge:

·   future sludge monitoring should include other substances of emerging concern – specifically the CIP2 researchers recommended monitoring of PFOS, BDEs and PAHs.

·   the CIP2 sludge study provided an insight into changes in trace substances concentrations through the sludge treatment process. Future investigations should include sampling of the sludge close to the final product to be applied to land, in order to allow more detailed assessment of the risks linked to sludge application to land.

·   the current Sludge Directive has been under revision for several years. The CIP2 researchers noted that it would be of value for the water industry to review sludge standards applied in other countries and to consult with Defra about likely future developments in UK legislation.

4.   Materials to Land Phase 2 – Site Audits

4.1   Scope of Works

An Environment Agency Officer and an AECOM staff member visited each Phase 2 subject site. The EA officer conducted an information audit with the site operator's representative while the AECOM staff collected samples of the waste and sent them to an AECOM subcontract laboratory for a suite of chemical analyses to characterise the nutrient content and presence of possible contaminants.

The site visits took place between 6th February and 13th March 2017.

4.1.1   Site Selection

Sewage sludge treated with lime and pig and poultry carcass ash were selected for sampling in this project because of the need to fill gaps in the EA's understanding of their composition and their use on land. These were not effectively sampled in Phase 1 because they are not spread to land under mobile plant permits.

The sewage sludge sites selected include waste management sites that are not located at or operated by a water company's WwTW. These sites were producing enhanced sewage sludge treated with lime.

The EA regulates intensive pig and poultry rearing farms; these include farms with more than:

·   40,000 places for poultry;

·   2,000 places for production pigs (over 30 kg); and

·   750 places for sows.

All the pig and poultry sites visited during the project were farms with active environmental permits.

Thirty subject sites were initially selected by the Environment Agency, comprising;

·   10 poultry sites;

·   10 pig sites; and

·   10 sludge treatment sites.

Where the operator could not accommodate the site visit, an alternative similar site was selected. However, one site, which held a permit to produce pigs, was found to be currently producing poultry, one sludge site ceased operation before the scheduled visit took place and a second sludge site had no waste available to sample. No alternative sludge treatment site visits could be arranged within the project timescale. The 28 sites actually audited were therefore:

·   11 poultry sites;

·   9 pig sites; and

·   8 sludge treatment sites.

4.1.2   Health and Safety

At the project outset, a generic Health and Safety Plan was drawn up incorporating EA guidelines on site visits to agricultural premises with AECOM standard Task Hazard Assessments. Prior to each site visit, a Site Specific Health and Safety Plan was compiled with known information about the site operation and location. This was reviewed with the EA officer on the day of the visit to include any last minute concerns.

4.1.3   Biosecurity

Full biosecurity measures were adopted to prevent possible spread of diseases (e.g. Avian Influenza, bluetongue) between farms, and these included use of disposable gloves and overalls, cleaning of all sampling equipment, boots and vehicle tyres with Virkon S disinfectant (or an alternative disinfectant provided by the farm as required) when arriving at or leaving sites.

AECOM and EA staff met up at locations away from the subject sites and travelled to the site together in a hired vehicle to minimise the risk of vehicles becoming a disease vector.

The site visits were scheduled such that the site staff had avoided all contact with pig or poultry for at least 72 hours prior to a visit to a pig or poultry site.

4.2   Sampling Methodology

For all sites visited, the objective was to collect samples of the waste designated to be spread on land for which there was information supplied by the operator during the audit.

The potential for cross contamination was minimised by using new or clean equipment to collect the waste samples. Disposable bulk bags were used to thoroughly mix the composite samples and disposable nitrile gloves were worn during the sampling process and changed between individual samples.

For all the wastes sampled, a composite sample was taken which was made up of a minimum of 12 incremental subsamples from different locations around the container or stockpile of waste available. The composite sample was then mixed thoroughly until homogenous, and then three subsamples were transferred into the laboratory-supplied containers to be sent for analysis.

Where samples were collected from sludge stockpiles, the surface layer of sludge was discarded and each subsample taken from a depth of approximately 100 to 300 mm depth. It is recognised that the composition of the sludge within the middle of the stockpile may differ from that of sludge at or near the surface of the stockpile, due to differences in temperature, moisture content and relative aerobic/anaerobic conditions within the stockpile. However, collection of samples from the centre of the stockpile was not feasible due to health and safety, time and logistical considerations. Any additional site-specific limitations to the waste sampling procedure than those noted above are recorded in the individual factual report for each site.

Samples were packed in insulated cool boxes (with frozen ice packs) and sent under chain-of custody protocols. They were hand delivered to a local courier depot for next-day delivery to the laboratory. The samples were analysed by an AECOM approved independent laboratory, ALS Environmental Ltd.

The full list of analytes scheduled is presented in Table 4-1 below. The analytical suites selected for the different samples collected are described in Section 4.2.1 and Section 4.2.2, following this table.

Table 4-1 - Analytical Suites

Suite A Metals

Chemical Group	Analytes	
Suite A - Metals - (Solids)	Aluminium	Manganese
	Antimony	Mercury
	Arsenic	Molybdenum
	Barium	Nickel
	Beryllium	Phosphorus
	Bismuth	Potassium
	Boron	Selenium
	Cadmium	Silver
	Calcium	Sodium
	Chromium	Strontium
	Cobalt	Tellurium
	Copper	Thallium

	Iron	Tin
	Lead	Titanium
	Lithium	Vanadium
	Magnesium	Zinc

Suite A

Chemical Group	Analytes	
Dioxins	1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin
	1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	1,2,3,7,8-Pentachlorodibenzo-p-dioxin
	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	2,3,7,8-Tetrachlorodibenzo-p-dioxin
	1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	
Furans	1,2,3,4,6,7,8,9-Octachlorodibenzofuran	1,2,3,7,8,9-Hexachlorodibenzofuran
	1,2,3,4,6,7,8-Heptachlorodibenzofuran	1,2,3,7,8-Pentachlorodibenzofuran
	1,2,3,4,7,8,9-Heptachlorodibenzofuran	2,3,4,6,7,8-Hexachlorodibenzofuran
	1,2,3,4,7,8-Hexachlorodibenzofuran	2,3,4,7,8-Pentachlorodibenzofuran
	1,2,3,6,7,8-Hexachlorodibenzofuran	2,3,7,8-Tetrachlorodibenzofuran
PCBs	Heptachlorobiphenyl, 2,3,3,4,4,5,5- (PCB 189)	Pentachlorobiphenyl, 2,3,4,4,5- (PCB 114)
	Hexachlorobiphenyl, 2,3,3,4,4,5- (PCB 156)	Pentachlorobiphenyl, 2,3',4,4',5- (PCB 118)
	Hexachlorobiphenyl, 2,3,3,4,4,5- (PCB 157)	Pentachlorobiphenyl, 2,3,4,4,5- (PCB 123)
	Hexachlorobiphenyl, 2,3,4,4,5,5- (PCB 167)	Pentachlorobiphenyl, 3,3,4,4,5- (PCB 126)
	Hexachlorobiphenyl, 3,3,4,4,5,5- (PCB 169)	Tetrachlorobiphenyl, 3,3,4,4- (PCB 77)
	Pentachlorobiphenyl, 2,3,3,4,4- (PCB 105)	Tetrachlorobiphenyl, 3,4,4,5- (PCB 81)
Suite A - Carbon	Organic Carbon, Total	Organic Matter, Total
Suite A - Inorganics	pH	Phosphate (Bicarbonate Extractable) as mg/l P
	Ammoniacal Nitrogen as N	Sulphur
	Conductivity @ 20 deg.C	Fluoride
	Neutralising value	Fluoride, acid soluble
	Nitrogen, Total	
Suite A - Metals - (Liquid)	Extractable Calcium	Extractable Potassium
	Extractable Magnesium	Extractable Sodium
Suite A – Polycyclic Aromatic Hydrocarbons	Acenaphthene	Dibenzo(a,h)anthracene
	Acenaphthylene	Fluoranthene
	Anthracene	Fluorene
	Benz(a)anthracene	Indeno(1,2,3-cd)pyrene
	Benzo(a)pyrene	Naphthalene
	Benzo(b)fluoranthene	PAH, Total Detected USEPA 16
	Benzo(g,h,i)perylene	Phenanthrene
	Benzo(k)fluoranthene	Pyrene
	Chrysene	
Suite A - Sample Description	Moisture Content Ratio (% of as received sample)	Soil Density
Suite A - Subcontracted: Organics	Iodide	Iodine
	PSD PAS100	Total plastic
	Total glass, metal and "other" fragments	Total stones >4mm in size

Bacterial Analysis Suite

Chemical Group	Analytes	
Bacteria Suite - Microbiological	Escherichia coli	Total Coliforms
	Salmonella	

Suite B

Chemical Group	Analytes	
Organo Metals	Dibutyltin	Tetrabutyltin

	Diphenyl Tin	Tributyltin
	Monobutyltin	Triphenyltin
	Monophenyl Tin	

Suite B - Combined Pesticides / Herbicides	Chlorothalonil	Heptachlor
	Baythroid	Heptachlor epoxide
	Cyhalothrin	o,p'-DDD (TDE)
	Cypermethrins(total)	o,p-DDE
	Deltamethrin	o,p-DDT
	Fenvalerate	o,p-Methoxychlor
	Isodrin	p,p-DDE
	Mirex	p,p-DDT
	Permethrin	p,p-Methoxychlor
	Aldrin	p,p-TDE (DDD)
	alpha-Hexachlorocyclohexane (HCH)	Pendimethalin
	beta-Hexachlorocyclohexane (HCH)	Permethrin I
	Chlordane (cis)	Permethrin II
	Chlordane (trans)	Phorate
	Dieldrin	Tecnazene
	Disulfoton	Telodrin
	Endosulphan I	Toxaphene
	Endosulphan II	Triadimefon
	Endosulphan sulphate	Triallate
	Endrin	Trifluralin
	gamma-Hexachlorocyclohexane (HCH / Lindane)	

Suite B - Miscellaneous Organics	Pentachloronitrobenzene	PFBA (Perfluoro-n-butanoic acid) 357-22-44
	1,2-Bis(pentabromophenyl) ethane	PFBS (Perfluoro-1-butanesulfonate) 375-73-5
	2,2',3,4,4',5'-hexabromodiphenyl ether (BDE-138)	
	2,2'',3,4,4''-pentabromodiphenyl ether (BDE-85)	PFDA (Perfluoro-n-decanoic acid) 335-76-2
		PFDoA (Perfluoro-n-dodecanoic acid) 307-55-1
	2,2',4,4',5,5'-hexabromodiphenyl ether (BDE-153)	PFHpA (Perfluoro-n-heptanoic acid) 375-85-9
	2,2',4,4',5,6'-hexabromodiphenyl ether (BDE-154)	PFHpS (Perfluoro-1-heptanesulfonate) 375-92-8
	2,2'',4,4'',5-pentabromodiphenyl ether (BDE-99)	
	2,2'',4,4'',6-pentabromodiphenyl ether (BDE-100)	PFHxA (Perfluoro-n-hexanoic acid) 307-24-4
		PFHxS (Perfluoro-1-hexanesulfonate) 355-46-4
	2,2'''',4,4''''-tetrabromodiphenyl ether (BDE-47)	PFNA (Perfluoro-n-nonanoic acid) 375-95-1
	2,3'''',4,4''''-tetrabromodiphenyl ether (BDE-66)	PFOA (Perfluoro-n-octanoic acid) 335-67-1
	2,4,4''''-tribromodiphenyl ether (BDE-28)	PFOS
	6:2-PTS 27619-97-2	Branched PFOS
		PFOS (Perfluoro-1-octanesulfonate) 1763-23-1
	Cyclohexane Extractable Matter	PFOSA (Perfluoro-octanesulfonamide) 754-91-6
	Galoxolide	PFPA (Perfluoro-n-pentanoic acid) 2706-90-3
	Hexabromocy clododecane (HBCDD)	PFUnA (Perfluoro-n-undecanoic acid) 2508-94-8
	Nonylphenol	
	Tonalide	Tris(1-chloro-2-propyl)phosphate
	Trimethoprim	Tris(2-chloroethyl) phosphate

Suite B - Semi-Volatile Organic Compounds	1,2,4-Trichlorobenzene	4-Nitrophenol
	1,2-Dichlorobenzene	Azobenzene
	1,3-Dichlorobenzene	bis(2-Chloroethoxy)methane
	1,4-Dichlorobenzene	bis(2-Chloroethyl)ether
	2,4,5-Trichlorophenol	Bis(2-chloroisopropyl)ether
	2,4,6-Trichlorophenol	bis(2-Ethylhexyl) phthalate
	2,4-Dichlorophenol	Butylbenzyl phthalate
	2,4-Dimethylphenol	Carbazole
	2,4-Dinitrotoluene	Dibenzofuran
	2,6-Dinitrotoluene	Diethyl phthalate

Suite		
	2-Chloronaphthalene	Dimethyl phthalate
	2-Chlorophenol	Hexachlorobenzene
	2-Methylnaphthalene	Hexachlorobutadiene
	2-Methylphenol	Hexachlorocyclopentadiene
	2-Nitroaniline	Hexachloroethane
	2-Nitrophenol	Isophorone
	3-Nitroaniline	n-Dibutyl phthalate
	4-Bromophenylphenylether	n-Dioctyl phthalate
	4-Chloro-3-methylphenol	Nitrobenzene
	4-Chloroaniline	n-Nitroso-n-dipropylamine
	4-Chlorophenylphenylether	Pentachlorophenol
	4-Methylphenol	Phenol
	4-Nitroaniline	Total SVOC TIC
Suite B - Subcontracted: Organics	Aminomethylphosphonic acid	Triclosan
	Glyphosate	
Suite B - Volatile Organic Compounds	1,1,1,2-Tetrachloroethane	Chloroethane
	1,1,1-Trichloroethane	Chloroform
	1,1,2,2-Tetrachloroethane	Chloromethane
	1,1,2-Trichloroethane	cis-1,2-Dichloroethene
	1,1-Dichloroethane	cis-1,3-Dichloropropene
	1,1-Dichloroethene	Dibromochloromethane
	1,1-Dichloropropene	Dibromomethane
	1,2,3-Trichlorobenzene	Dichlorodifluoromethane
	1,2,3-Trichloropropane	Dichloromethane
	1,2,4-Trimethylbenzene	Ethylbenzene
	1,2-Dibromo-3-chloropropane	Isopropylbenzene
	1,2-Dibromoethane	Methyl Tertiary Butyl Ether
	1,2-Dichloroethane	n-Butylbenzene
	1,2-Dichloropropane	o-Xylene
	1,3,5-Trimethylbenzene	p/m-Xylene
	1,3-Dichloropropane	Propylbenzene
	2,2-Dichloropropane	sec-Butylbenzene
	2-Chlorotoluene	Styrene
	4-Chlorotoluene	Tert-amyl methyl ether
	4-Isopropyltoluene	tert-Butylbenzene
	Benzene	Tetrachloroethene
	Bromobenzene	Toluene
	Bromochloromethane	trans-1,2-Dichloroethene
	Bromodichloromethane	trans-1,3-Dichloropropene
	Bromoform	Trichloroethene
	Bromomethane	Trichlorofluoromethane
	Carbon Disulphide	Vinyl Chloride
	Carbontetrachloride	VOC TICs
	Chlorobenzene	

The contents of analytical suites shown in Table 4-1 was as requested by and agreed with the Environment Agency, and also accounted for analytical laboratory capabilities in effect at the time of the project.

4.2.1   Pig and Poultry Sites

At each site, one composite sample of ash was collected and three subsamples transferred from this into the laboratory-supplied containers to be sent for analysis. These were each scheduled for the Suite A list of analytes (including metals).

The composite samples of ash were taken from the ash collection receptacle (typically a dustbin or steel drum adjacent to the incinerator), or directly from the incinerator.

Where the site operator did not allow access to the incinerator location (due to concerns about biosecurity), a bulk sample was provided that was collected by the site operator. This was treated in the same way as a composite sample but AECOM were unable to guarantee that the sample provided was representative of ash in the incinerator or ash receptacle.

4.2.2 Sludge Sites

For sites producing enhanced sewage sludge treated through the addition of lime, the aim was to collect as received samples of the untreated sludge (as it arrived at the site from the water treatment works), and treated samples of the same batch of sludge following mixing with lime.

Where possible, two composite samples (12 incremental samples each) were collected from the stockpile of untreated sludge. Each composite sample was sub-divided into three subsamples giving a total of six subsamples which were each scheduled for bacterial analysis and for metals analysis.

Where freshly treated sludge was available, two composite samples (12 incremental samples each) were collected from the stockpile of treated sludge. Each composite sample was sub-divided into three subsamples giving a total of six subsamples which were each scheduled for bacterial analysis. Three of the six subsamples were scheduled for Suite A analysis (including metals) and the other three for Suite B analysis.

If no sludge was available to sample at the treatment location, previously treated sludge was sampled from an S3 exemption field stockpile.

In an addition to the initial scope of works, where available, a sample of the lime used for treatment was sampled, and scheduled for metals analysis.

4.3 Analytical Issues

4.3.1 Physical Form of the Wastes Sampled

4.3.1.1 Ash Sites

The ash samples were extremely dry and friable (dusty) with high calcium content. The particle size of poultry ash was typically fine grained with occasional fragments of larger bones including legs and wings. The pig ash tended to be more heterogeneous in size, varying from sand-sized ash particles to much larger bone fragments up top 10 cm across, reflecting the much larger skeletons of sows versus layers.

The presence of elevated concentrations of calcium resulted in matrix interference and significant suppression on the analytical detection limits of other alkali metals. The laboratory ran repeated analyses with dilutions applied but for some samples, was unable to obtain replicable or consistent results due to the level of interference experienced. As a result, for some sites the laboratory was unable to report any results for alkali metals.

For many of the ash samples, the fluoride analysis could not be completed using the spectrophotometric method originally proposed by the laboratory as the samples were too strongly coloured. For these samples, an ion chromatography method (Dionex) was used instead which had a higher method detection limit of 11.5 mg/kg, as opposed to 0.046 mg/kg for the spectrophotometric method.

4.3.1.2 Sludge Sites

Samples of untreated and treated sludge typically had high moisture and organic matter contents. Although the laboratory dried the samples prior to grinding, they were unable to hand crush and sieve them as per the standard preparation method, due to the high plasticity of the dried samples. This prevented the measurement of sample density and, for some samples, meant that determination of bicarbonate extractable phosphate was not possible.

Analysis of chlorothalonil (a pesticide included within Suite B) presented the laboratory with a challenge, as the compound breaks down under alkaline pH conditions, such as those present in a sludge treated with lime. Furthermore, chlorothalonil can bind strongly to organic matter, making it difficult to analyse in the presence of organic matter. For some of the sludge analyses, the laboratory removed chlorothalonil from the analytical suite to maintain the limits of detection for the other analytes tested.

4.3.2   Microbial Analysis

The method used for detection of Salmonella species in samples of untreated and treated sludges is based on series of serological and biochemical reactions which select the target organism growth while inhibiting other organisms with similar habitat such as coliforms. The results of the analysis are reported as the presence or absence of salmonella in a 20 g aliquot of wet weight sludge. This method is currently unaccredited by UKAS (United Kingdom Accreditation Service). This meant that analysis of lime treatment on the levels of Salmonella was a simple present/absent test, and the levels could not be assessed against the limits used in the Smart Form.

Serial dilution tests were used to measure the concentration of Escherichia coli and Total Coliforms in sludge samples with a method called the most probable number (MPN). The MPN method involves multiple dilutions of the sample and assessment of the relative presence or absence of bacteria in each dilution. The "outcome" (i.e. the number of tubes and the number of tubes with growth at each dilution) implies an estimate of the original, undiluted concentration of bacteria in the sample. In order to obtain estimates over a broad range of possible concentrations, the laboratory used serial dilutions, incubating tubes at several dilutions. For a given array of dilutions applied there is a maximum value that can be enumerated meaning that the results, particularly for the untreated sludge, were often expressed as >2,010,000 MPN/g. For one site (A3) the analysis was completed on two dilutions only in comparison with other samples where a greater number of dilutions were assessed, with the results reported as >20,100 MPN/g. This meant that it was not always possible to assess the exact scale of the reduction in these microbes between untreated and treated sludge. Additionally, these units were different to those used in the Smart Form and it was not possible to convert between units.

4.3.3   Dioxins, Furans and Dioxin-like PCBs

Dioxins, furans and dioxin-like PCBs were analysed to low levels using high resolution gas chromatography mass spectrometry (HRGC-MS). Samples required a pre-treatment process of solvent extraction and a chromatographic clean-up prior to the HRGC-MS analysis. For this analysis, the reporting limit is a function of the recovery on each sample; hence a detection limit for the analytical method has not been reported.

4.4   Factual Reporting

4.4.1   Pig and Poultry Sites

Eleven of the subject sites were poultry production sites. Four of these raised broiler chickens, two raised broilers and layers, two raised pullets and layers, one raised layers only and two raised ducks. Factual reports for individual pig and poultry sites are presented in Appendix A.

Of the nine pig production sites, five raised production pigs over 30 kg in weight, three raised production pigs and breeding sows, and one raised production pigs, sows and piglets.

4.4.1.1   Incinerator Operation

Each of the sites' incinerator installations was reportedly designed and operated to comply with Animal and Plant Health Agency (APHA) approval as low capacity incinerator sites burning less than 50 kg of material per hour. They each were of a two chamber design with the secondary chambers fitted with afterburners to hold exhaust gases at 850°C for two seconds. Common brands of incinerator identified on the farms included Addfield (three poultry farms and two pig farms), Masterburn (three pig farms), and Waste Spectrum (four poultry farms and two pig farms).

To show that the correct temperatures are being achieved, the operators must record temperatures of the exhaust gas, as a minimum every two hours during the burn cycle, and retain records for a minimum of 10% of incinerations. In addition, the operators are required to retain the annual service record for the incinerators.

Only one site (E6) did not produce documentary evidence of current APHA inspections, although the operator stated that it had been inspected. On some farms, the weight of ash produced during each burn was recorded, while others estimated the volumes produced.

All of the sites reported that the incinerators were only used for the disposal of carcasses, with the following observations:

·   at B3 and A4, egg waste including shells was incinerated alongside the poultry carcasses;

·   at D3, poultry carcasses were placed in plastic bags which were incinerated with the carcasses; and

·   one of the pig production sites (E6) did not remove plastic ear tags attached to the sows before incineration, while a second site (E4) could not confirm whether the ear tags were removed.

All of the sites indicated that other wastes were collected by waste contractors for off-site disposal and no additional wastes were placed in the incinerator.

The frequency of burn cycles varied for each farm from once a fortnight to three times a week based on the number of animals in the batch, the size of stock at each stage of production and the mortality rate. Operators estimates of the quantity of ash produced each year ranged from 52 kg to 13 tonnes.

4.4.1.2   Ash Spreading

The ash was either stored in the incinerator burn chamber itself until it required emptying, or stored in a bin nearby. Incinerators or the buildings they were housed in were generally kept locked. Typically, incinerators were located away from buildings where the stock was reared and were inaccessible to animals. The incinerators and ash receptacles were generally secured with a padlock or similar to restrict access.

Waste exemption U15 allows operators to mix ash from burning pig or poultry carcasses with slurry and/or manure and spread it on farmland. The ash must be mixed with at least an equal quantity of manure and must be spread on the same farm where the pigs or poultry died and were then incinerated. The spreading rate for the ash/manure mixture should be such that the quantity of ash spread does not exceed 150 kg per hectare per year (kg/Ha/yr). Nine of the farms also supplied information regarding the quantity of manure generated. For seven of these the ratio of ash to manure generation was less than 1 in 1000, although at most sites it was reported that in practice the ash is mixed with a part of the manure stockpile giving a locally higher ratio of ash to manure. One site (B3) kept the manure from pet alpacas and ponies to mix with the ash at a 50:50 ratio before spreading to an area of grass.

Site B4 reportedly disposed of the ash from the incinerator by tipping it directly onto grass nearby, with no mixing with slurry or manure. A further farm (D6) exported manure to neighbouring farms and could not guarantee that ash from the incinerator was not included within the manure.

Sixteen of the sites reported that the ash/manure mixture would be spread on land used for arable crops, while just one site (D3) reported that it would be spread on grazing land. Waste exemption U15 limits the amount of ash spread to 150 kg per hectare in a 12-month period. Where the area of land available for spreading was reported (ten out of the 20 ash sites), the spreading rate of ash could be estimated and ranged from 0.0005 to 0.07 kg/Ha/yr.

For most of the sites, the ash and manure mix was incorporated into the soil, however, at two sites (B3 and C3) it was reportedly surface spread without incorporation.

None of the farms visited was able to provide soil testing results for the fields where the ash was to be spread.

4.4.2 Sludge Sites

Eight sites were visited which produced enhanced sewage sludge which has been treated by the addition of lime. Five of the sites were supplied with digested and dewatered sludge from WwTW operated by Yorkshire Water, two from WwTW operated by Thames Water, and one from WwTW operated by United Utilities. Factual reports for individual sludge sites are presented in Appendix B.

At three of the sites (A2, B2 and E5), samples of sludge were only available from S3 exemption field stockpiles that had been previously treated. On all the other sites the samples were collected at the location where the lime treatment took place. Samples of untreated sludge were collected from four of the sites.

At six of the sludge treatment sites visited, a sample of the lime product being used to treat the sludge was also collected. These lime samples were analysed for the metals component of Suite A, to assess the potential contribution from lime to the metal content of the treated sludge. The results of these analyses are summarised in Appendix C4 and presented in full in the laboratory analysis certificates appended to the individual site factual reports.

4.4.2.1   Lime Mixing

The calcium concentrations ranged from 493,000 mg/kg (49.3%) in the sample of Bolshaws - Hydrated Lime collected from site B2 to 755,000 mg/kg (75.5%) in the sample of lime supplied by Tata Steel collected from site E2.

The following metals were detected above the respective analytical laboratory method detection limits (MDLs) in all of the six lime samples analysed:

· Aluminium	· barium
· boron	· cadmium
· chromium	· cobalt
· copper	· iron
· lithium	· magnesium
· manganese	· molybdenum
· nickel	· phosphorus
· potassium	· sodium
· strontium	· titanium
· vanadium	· zinc

The following metals were not detected above the respective MDLs in any of the six lime samples analysed:

· bismuth	· mercury
· selenium	· silver
· tin	

The following differences in metal concentrations between the various limes were identified:

· antimony was only detected above the MDL in Bolshaws - Hydrated Lime;

· lead was only detected above the MDL in Singleton Birch – Granulime;

· tellurium was only detected above the MDL in Tata Steel - Ground Burnt Lime; and

·   arsenic and thallium were only detected above the MDL in the sample of unknown Tata Steel Lime.

The lime used for the treatment varied across the sites but was supplied by just three producers: Singleton Birch, Tata Steel and Bolshaw Industrial Powders. The two sites using lime supplied by Bolshaws (A3 and B3) were using products composed of lime in calcium hydroxide form ($Ca(OH)_2$) as opposed to lime in calcium oxide form (CaO). One of the Bolshaws products was Cubicle Care, a special mix of two forms of hydrated lime used for mastitis control in dairy herds. The Cubicle Care has a coarser, more granular particle size which may be less effective than the typical powdered lime. All the sites used dry lime in a powder or granular form. Details of the lime used for the treatment are summarised in Table 4-2 below.

The mixing method observed or reported at all sites was to use a tele handler or shovel loader to move and mix the lime and sludge on the concrete pad. The stockpiles of treated sludge were, in all cases, described as heterogeneous with some areas of the stockpile having visually less lime than other areas. This indicates that the mixing method used was ineffective at bringing all the sludge into contact with a sufficient quantity of lime. Typically, the untreated and treated lime piles were kept separate on different sides of the pad.

The Defra Code of practice for the agricultural use of sewage sludge describes the process as "*Addition of lime to raise pH to greater than 12.0 and sufficient to ensure that the pH is not less than 12.0 for a minimum period of 2 hours.*" Operators have to measure and record the pH of the treated sludge to confirm this.

Monitoring and recording of pH values after treatment was reported at each of the subject sites. It was noted that the treated sludge was often not homogenous with clumps of lime visible and that it was not possible to confirm which parts of the stockpile had been sampled for pH analysis and if the pH measurements made by the operator staff were representative of the whole stockpile.

According to the calibration records provided by the operators, calibration of the pH probes used by the operators was in some cases, occurring less often than recommended. It was also not clear whether the calibration consisted of standardisation against a single calibration point or multiple calibration points.

Only three of the treated sludges sampled by AECOM had a pH above 12. The lowest pH values were from sites A2 (pH 8.1), B2 (pH 7.9) and E5 (pH 7.2). At these three sites, lime treatment was not observed and the samples were collected from the S3 field stockpiles. The sludge in these three stockpiles had (according to the operators) been treated with lime between five days and three months prior to the samples being collected. Where available, details on the time elapsed since treatment for each of the sludges sampled are provided in Table 4-2 below.

The Environment Agency Operational Instruction 585_11 "*Interaction between lime and sludge for the purpose of lime stabilisation for use with mobile plant permits*" states that "*Addition of typically 20-40% calcium oxide or equivalent of calcium hydroxide per unit of dry solids is capable of producing a treated sludge*"

Operators reported dosing rates in terms of the number of bulk bags of lime used per truckload of sludge. These reported dosing rates were between 3% and 7% (by wet "as received" weight). In order to compare the dosing rates with those in the EA Operational Instruction 585_11, the moisture content of the untreated sludge has been used (for the sites where such samples were available) to calculate the lime dosing rate as a percentage of the dry solids content of the untreated sludge. These results are summarised in Table 4-2 below, and with the exception of site D2 (at 10%), the dosing rates exceeded the lower value of 20% provided in the operational instruction.

4.4.2.2   Treatment Locations

Treatment locations were generally located well away from built environments and were typically constructed on concrete pads surrounded by concrete blocks, straw bales or earth banks. Liquid runoff was typically collected in a sump at the edge of the pad and recirculated over the stockpiles,

although some limitations with drainage were noted. At one site (E2), it was noted that the treated sludge stockpiles were open to grazing sheep in the same field.

4.4.2.3   Spreading Locations

The Sludge (Use in Agriculture) Regulations 1989 (SUiAR) requires that the soil on agricultural land where sewage sludge is to be spread must be analysed at a minimum for the list of metals in the regulation once every twenty years. The site operators of four of the sites were able to share soil analysis results but in no case was it possible to match the results to the fields on which the sludge sampled by AECOM was destined to be spread.

SUiAR also requires that: *"Representative samples of sludge intended to be used on agricultural land shall be taken after processing but before delivery to the user*." Six of the eight site operators were able to share sludge analysis reports although the analysis supplied by site E5 was dated October 2016. In each case, the analysis included: pH, Lime Equivalent as CaCO3, Neutralising Value, Ammonium Nitrogen, Nitrate Nitrogen, Total Nitrogen, Total Carbon, Organic Matter, Oven Dry Matter, Conductivity, Fluoride, Aluminium, Arsenic, Cadmium, Calcium, Chromium, Copper, Iron, Lead, Magnesium, Manganese, Mercury, Molybdenum, Nickel, Phosphorus, Potassium, Selenium, Sodium, Sulphur, and Zinc.

Four of the six analysis reports comprised results for only one treated sludge sample. No additional details were provided on how the samples were collected (e.g. whether they were grab samples or composite samples and whether they were sampled from the surface of the stockpile, etc.). Given the heterogeneous nature of the treated sludge observed (particularly with respect to the proportion of lime) these sludge samples may not be representative of the entire sludge stockpile.

Seven of the sites reported that the sludge would be spread on land used for arable crops. The other site (D4) did not provide any information on intended land use.

4.4.2.4   Microbiological Analysis

Samples of treated sludge collected from all eight sites and of untreated sludge collected from four of the sites were scheduled for microbiological analysis including Escherichia coli, Total Coliforms, and presence/absence of Salmonella. A summary of the micro-biological analysis results is presented in Table 4-2 below.

Table 4-2 - Lime Treatment Details and Microbiological Analysis

Lime Treatment	Site	A2	A3	A6	B2	D2	D4	E2	E5
Lime supplier/ Type		Bolshaws Cubicle care	Tata Steel Ground Burnt Lime	Tata Steel (Type Unknown)	Bolshaws Hydrated Lime	Singleton Birch Granulime	Tata Steel Ground Burnt Lime	Tata Steel (Type Unknown)	Singleton Birch Granulime
Form of Lime		$Ca(OH)_2$	CaO	Unknown	$Ca(OH)_2$	CaO	CaO	Unknown	CaO
Calcium Content	% Dry Solids			60%	49%	67%	67%	76%	55%
Reported Lime Dosing Rate	% As Received	5%	7%	5%	4%	3%	5%	5%	Unknown
Average Untreated Sludge Dry Solids Content	% AR		28.3			30.2	26.7	24.2	
Lime Dosing Rate	% Dry Solids		24%			10%	20%	21%	
Average pH of Treated Sludge		8.1	12.0	12.4	7.9	10.8	12.3	11.0	7.2
Microbiological analysis									
Untreated Sludge	Escherichia coli		>20,100			32,400	>2,010,000	885,000	
	Total Coliforms		>20,100			1,650,000	>2,010,000	>2,010,000	
	Salmonella		Present			Present	Present	Present	
Treated Sludge	Escherichia coli	1,650	>20,100	<60	17,800	53	<60	8,850	306
	Total Coliforms	2,880	>20,100	<60	165,000	750	<60	47,800	130,000
	Salmonella	Absent	Present		Present	Absent	Absent	Absent	Absent
% Pathogen Reduction from Untreated Sludge	Escherichia coli					99.836%	> 99.997%	99.000%	
	Total Coliforms					99.955%	> 99.997%	>97.622%	
Time since treatment	Time since treatment	5 days	<1 day	Unknown	>34 days	<1 day	<1 day	Unknown	> 3 months
Sampling location	Sampling location	Field	Compound	Compound	Field	Compound	Compound	Compound	Field

The ADAS Safe Sludge Matrix (Guidelines for the application of sewage sludge to agricultural land), April 2001, 3rd edition. defines conventionally treated sludge as that which "*has been subjected to defined treatment processes and standards that ensure at least 99% of pathogens have been destroyed.*" This document defines enhanced treated sludge as that which "*will be free from Salmonella and will have been treated so as to ensure that 99.9999% pathogens have been destroyed (a 6-log reduction)."*

The sludge as received from the WwTW, referred to in this project as "untreated sludge", was described as "dewatered and deragged sludge" (Sites A3, A6, and E2) or "digested cake" (site D4).

Escherichia coli and total coliforms were detected at levels greater than 20,100 MPN colony forming units (cfu)/g and Salmonella was found to be present in all four samples of untreated sludge. In three of the samples, total coliforms were detected at levels greater than 1,600,000 MPN cfu/g.

The percentage pathogen reduction from untreated sludge to lime treated sludge could be calculated for three of the sites. A 4-log reduction in pathogens was only observed at site D4. As the Escherichia coli and total coliforms levels could only be reported as greater than an upper limit, it was not possible to assess if the 6-log reduction for enhanced treated sludge had been achieved.

Salmonella was determined to be present in samples of lime treated sludge from two of the sites (A3 and B2). At A3, CaO was used for treatment, whereas for B2, $Ca(OH)_2$ was used, so the presence of salmonella did not appear to be dependent on the type of lime used. The detection of salmonella in the lime treated sludge suggests lime treatment of the sludge either did not successfully kill off the salmonella, or that the treated sludge was re-infected with salmonella after being placed in stockpiles. Either way, the identification of salmonella in lime treated sludge is a concern. The presence of Salmonella means that the sludges would not meet the definition of enhanced treated sludge.

4.5   Analytes Detected in Waste Samples

The summary of detected analytes is included in the results summary tables in the following appendices:

Pig and poultry ash samples: C.3, C.7, and C.11

Sludge samples: C.4, C.8, C.12, and C.15

These findings will be discussed in more detail in Section 5.

4.6   Data Evaluation Using the EA Smart Form

4.6.1   Methodology

The Smart Form (previously called the Decision Support Tool) is an Excel workbook. It was developed by the Evidence Directorate of the EA to support the National Permitting Service (NPS) in the regulatory assessment of applications for deployment under a Standard Rules Permit (SR2010 No4) for mobile plant for landspreading (land treatment resulting in agricultural or ecological benefit).

The Smart Form was developed to make it easier for EA staff to collate relevant information about a deployment, to check key details, and provide an initial and generic assessment of the agricultural and ecological benefits as well as the potential impacts and risks to soil quality and human health.

Importantly, the Smart Form is a tool designed to assist permitting staff in assessing a deployment and should not be used in isolation to determine a decision on whether to approve a particular deployment.

The Smart Form comprises a series of spreadsheets (modules), some which are available for editing, and some hidden spreadsheets which contain the calculations and reference data. More information on required inputs for the model is presented below.

Prior to rolling out the Smart Form for widespread internal use, the EA wanted to test the performance of the Smart Form with a large diverse dataset from real deployments and agricultural benefit statements to identify deficiencies, areas of improvements and potential changes to the model. Phase 1 of the Materials to Land project afforded such an opportunity.

For Phase 2, the Smart Form has been used to assess risks to the environment from the application of lime treated sewage sludge, or pig and poultry ash, to land.

The use of the Smart Form to assess risks associated with the spreading of pig and poultry ash, or sewage sludge, is described in more detail in the following sections.

4.6.2   Selection of Input Parameters

The EA's electronic LPD1 Smart Form has been used to assess risks to human health and the environment and, if possible, benefits associated with sludge and ash spreading. Given the potential gaps in the input data, assumptions and generalisations have been made when using the Smart Form. This may have restricted the Smart Form's ability to fully assess risks for individual sites, but these results provide an initial assessment of the risk at each site and contribute to the overall understanding of the risk and benefit of spreading these materials. The simulation results may also indicate where more detailed assessment is needed to better understand the site-specific risks. The assumptions made are noted in Section 4.6.3, plus Table 4-3 and Table 4-4, below.

The Smart Form has been used as follows:

· to assess risks and benefits by only loading the key inputs into the Smart Form. Details of operators, farmers, etc. have not been completed. As a result, the Smart Form has not been used to assess issues associated with completeness of information provided to the EA;

· to assess one waste - i.e. the waste sampled during the visit to that site (ash or treated sludge). The waste spreading (tonnage and rate) has been based on the available data. When rates/tonnage were not available, these were estimated based on data from other sites;

· inputs for chemical analytes in the waste (PTE and POP) were the maximum concentration detected in the three composite samples of waste collected at that site;

· if soil data for fields spread was available, it was input into the Smart Form and used in the assessment of risks and benefits, otherwise the national soil and herbage soil background quality data embedded in the Smart Form was used;

· where there was uncertainty (e.g. crop types or spreading rates) then the potential variations were run as different scenarios in the Smart Form for that site; and

· where there was insufficient data on soil / crop types the Smart Form was run for risk assessment only.

The Smart Form has been run for the Sludge, Human Health Quantitative Risk Assessment (HH QRA), Ecological Quantitative Risk Assessment (Eco QRA) modules, and, where possible, the Benefits assessments.

The Smart Form contains in-built databases for PTE and POP properties, background concentrations and regulatory limits. Where an analyte is absent from the database or key properties are missing, it cannot be fully assessed with the Smart Form. Detected analytes for which no assessment could be undertaken are listed in Table 4-5. Analytes for which at least some assessment was possible are excluded from the table.

The risk assessments undertaken for this project assumed background concentrations based on the in-built soil survey data within the Smart Form, taken from UK or European studies. Where no data were available, soil enrichment could not be quantified and was instead reported as 'high'. This was the case for some of the assessed POP, including ethylbenzene, naphthalene, phenol, toluene and xylene.

For the assessment of PTE covered by the Code of Practice for Agriculture Use of Sewage Sludge (COP) (DEFRA, 1996), the Smart Form assumes the background concentration in soil is equal to the

95th percentile value from these surveys. For the Human Health and Ecological Risk Assessments, the Smart Form assumes that the background concentrations in soil for PTE and POP chemicals is equal to the median value.

In addition to the assessment of risks from PTE and POP, the Smart Form is designed to assess benefits and risks from application of nutrients (nitrogen, phosphorus, potassium, magnesium, sodium and sulphur). For the Phase 2 sites, benefits, and related risks, were not assessed given the limited data available for soil properties in the fields being spread.

Risks from microbiological pathogens (Salmonella and E. Coli) have not been assessed in the Smart Form, as analytical data could not be obtained in the units required by the Smart Form (CFU/g AR), or converted to these units. E. Coli results were reported by the laboratory in MPN/g and Salmonella was reported as either absent or present.

4.6.3 Smart Form Inputs and Assumptions

Key inputs parameters and assumptions for the assessment of risks from the spreading of treated sewage sludge are shown in Table 4-3.

Table 4-3 - List of Selected Input Parameters and Assumption – Treated Sewage Sludge Sites

Parameter	Input Selected	Assumptions
List of Wastes (LoW) code	19 08 05	Residual sludge from sewage plants treating domestic or urban waste waters.
Physical form	Stackable	Solid form of waste
Spreading rates T/Ha/Yr As Received		Up to four inputs for used for each site. These were based on:
Rate 1 ("Fields" 1 to 4)	Site-specific	Estimated maximum rate to stay within regulatory limits[1] based on PTE analysis data;
Rate 2 ("Fields" 5 to 8)		50% of estimated maximum rate;
Rate 3 ("Fields" 9 to 12)		150% of estimated maximum;
Rate 4 ("Fields" 13 to 16)		Rates reported in the Audit Information where available.
Soil Texture	Site-specific	From UKSO[2] at the location of the receiving field
Benefiting Crops	Site-specific	Based on data provided in the Audit Information
Organic matter content % w/w	5.085	Based on Geometric Mean of M2L Phase 1 soil data
Soil pH	7.3	Based on Geometric Mean of M2L Phase 1 soil data (7.265)
Overall application method for waste to field	Site-specific	Based on data provided in the Audit Information

[1]. The Sludge (Use in Agriculture) Regulations 1989. (This simulation assumes the maximum permissible quantity of a PTE is spread in a single application).

[2]. UK Soil Observatory (UKSO): http://mapapps2.bgs.ac.uk/ukso/home.html (accessed May 2017)

Key inputs and assumptions for assessment of pig and poultry ash are in Table 4-4.

Table 4-4 - List of Selected Input Parameters and Assumption – Pig and Poultry Ash Sites

Parameter	Input Selected	Assumptions
List of Wastes (LoW) code	19 01 12 B1	Wastes from the incineration and pyrolysis of waste: ash from the incineration of pig and poultry carcasses at premises used for agriculture only.
Physical form	Stackable	Solid form of waste
Spreading rates T/Ha/Yr As Received		Up to four inputs for used for each site. These were based on:
Rate 1 ("Fields" 1 to 4)	0.15	Maximum Stipulated in U15 Exemption (0.15T/Ha/Yr)
Rate 2 ("Fields" 5 to 8)	0.075	50% of this maximum
Rate 3 ("Fields" 9 to 12)	0.3	200% of this maximum;
Rate 4 ("Fields" 13 to 16)	Site-specific	Rates derived from estimates for annual ash generation and land available for spreading reported in the Audit Information.
Soil Texture	Site-specific	From UKSO[1] at the location of the receiving field
Benefiting Crops	Site-specific	Based on data provided in the Audit Information
Organic matter content % w/w	5.085	Based on Geometric Mean of Phase 1 soil data
Soil pH	7.3	Based on Geometric Mean of Phase 1 soil data (7.265)
Overall application method for waste to field	Site-specific	Based on data provided in the Audit Information

[1]. UK Soil Observatory: http://mapapps2.bgs.ac.uk/ukso/home.html (accessed May 2017)

Given potential uncertainty and variability in benefitting crops and spreading rates, between 12 and 16 scenarios were run for each site, to assess the effect of these different input parameters on the estimated level of risk.

Each Smart Form was run for the following modules:

· Sludge Values - comprising of soil concentrations post spreading; long term average application rates; and assessment of risks to human health and the environment, based on guideline values given in the COP;

· Human Health Quantitative Risk Assessment (HH QRA) - comprising estimation of soil concentrations post spreading; enrichment; and assessment of risks from PTEs not covered by the COP, plus POPs, through uptake by crops or livestock and exposure via the food chain; and

· Ecological Quantitative Risk Assessment (Eco QRA) - comprising estimation of soil concentrations post spreading; enrichment; and assessment of risks from PTEs and POPs not covered by the COP, through comparison of resulting soil concentrations against Soil Screening Values (SSV) protective of wildlife, including plants, soil invertebrates, birds, mammals and the microbial function of soil.

The Smart Form inputs and assumptions for each site are presented in the site-specific Interpretative Reports in Appendix B.

4.6.4   Assessment of Potential Receptors

In addition to the use of the Smart Form, where the locations of operations and spreading were known, then publically available web-sites were reviewed to identify potentially sensitive receptors that could be adversely affected by waste spreading including surface water, ecological receptors (e.g. Sites of Special Scientific Interest (SSSI)) and groundwater receptors (e.g. Source Protection Zones (SPZ), Nitrate Vulnerable Zones (NVZ), Safeguard Zones).

It is noted that although the Smart Form does contain a spatial analysis function to identify such receptors, it was not possible to use it on the current project as this module is only available internally to EA staff. Instead, the following publically accessible websites were reviewed:

·   Environment Agency, What's in Your Backyard?: http://apps.environment-agency.gov.uk/wiyby/;

·   British Geological Survey: http://mapapps2.bgs.ac.uk/geoindex/home.html; and

·   Natural England: http://www.natureonthemap.naturalengland.org.uk/MagicMap.aspx.

Where it was not possible to identify specific fields spread, the assessment was generalised to the site area. This was the case for all Ash sites and some Sludge sites. Presence, and where possible, the approximate distance and vector of the potential receptors were reported. The results of this assessment site are presented in the site-specific Interpretative Reports in Appendix B.

4.7   Assessment of Risks

4.7.1   Pig and Poultry Sites

No risks to human health or ecological receptors were flagged by the Smart Form for the POP / PTE chemicals and scenarios modelled for the pig and poultry ash sites.

Potential enrichment of the soil (>1% increase compared to national background levels) was identified for silver and naphthalene. However, no silver concentrations above the method reporting limit were detected in the ash samples. In order to allow the Smart Form to be run, and in the absence of concentrations for silver, the method reporting limits for silver were used as inputs, and thus the potential enrichments identified were theoretical. This assessment indicates low levels of silver present in ash could lead to enrichment in soils at levels which may pose a risk to the environment.

A theoretical potential enrichment of the soil with naphthalene was identified at sites A7, A8, B3, B6, C1, C2, C3, D3, D5, and D6, at the reported spreading rates. However, no background soil concentration for naphthalene is available for the Smart Form, so a percentage increase could not be calculated. Also, it was noted that naphthalene was not detected in ash samples collected from C3, D3, and D6, and as with silver above, in the absence of detected concentrations of naphthalene, the method reporting limits were used as inputs. Given the relatively low boiling point of naphthalene of 218°C, the presence of naphthalene in the pig and poultry ash could reflect either incomplete combustion or potentially result from subsequent absorption of naphthalene by the ash after incineration.

Theoretical enrichment of the soil with antimony was identified for site B3, when the model was run with an assumed spreading rate equal to the maximum permitted by the U15 Exemption (i.e. 150kg/Ha/yr.). No enrichment was identified when the reported spreading rate for this site was modelled.

For pig and poultry ash the bulk of the nutrient input will be provided by the organic matter within the slurry and manure mixed with the ash. In the absence of specific data relating to the manure and slurry, the relative proportion of slurry mixed with the ash, and the existing level of nutrients in the soil, there was insufficient information to assess benefits and risks from the spreading of nutrients in the waste. It was noted that at most farms, a significantly larger volume of manure and slurry was generated at the pig and poultry sites relative to the volume of ash, and the ratio of slurry to ash was expected to be significantly higher than 1:1.

A limited number of sites were noted to have surface water courses, or groundwater SPZ, within the area of the farm, and thus these could potentially be receptors to contamination resulting from spreading. However, in the absence of details on specific fields being spread, and the associated relative distances between the fields and the receptors it was not possible to assess the potential risks in more detail.

The assessment results for each site are presented in the individual Interpretative Reports for each site attached in Appendix B.

4.7.2   Sludge Sites

Key results for the assessment of risks from the spreading of treated sewage sludge were are follows. The assessment results for each site are presented in the individual site Interpretative Reports in Appendix B.

- Sludge (Use in Agriculture) Regulations:
  - at the reported sludge spreading rates for site A2 (24 T/Ha/yr) the rate of application of fluoride was noted to exceed the maximum permitted annual application rate of 20 kg/Ha/yr[7]. The exceedance of the maximum permitted annual application rate assumes yearly application at the modelled rate over a ten year period. Actual annual application rates in preceding years may vary from this. Further assessment of long term enrichment of this PTE at this site may therefore be advisable;

- Human Health Quantitative Risk Assessment (HH QRA):
  - concern over risks to human health through PTE or POP entering and persisting within the food chain was flagged for POP chemicals including benzo(a)pyrene, dioxins, furans and dioxin-like PCBs at all five of the sites assessed and for which spreading rates were provided (A2, A3, B2, D2, and E2). The percentage increase above background for benzo(a)pyrene ranged from 4.4% at site D2 to 45.4% at site B2. The percentage increase above background for dioxins, furans and dioxin-like PCBs ranged from 1.25% at site E2 to 18.6% at site A2. These risks were also flagged for all sites at all simulated application rates and crop types in the scenarios modelled;
  - risk to human health via exposure through the food chain was also flagged for manganese at site A2, where the percentage increase above background was 1.15%. The level of risk varied with respect to application rate;

- Ecological Risk Assessment (Eco QRA):
  - no risks to soil ecological receptors were flagged for the PTEs, POPs and scenarios modelled. However, Soil Screening Values for Assessing Ecological Risks (SSVs) were not available for all substances detected;

- Enrichment:
  - thirteen of the modelled POP / PTE were simulated to result in soil enrichment (>1% increase compared to national, background levels) when modelled at the reported spreading rates. These were benzo[a]pyrene, ethylbenzene, naphthalene, perfluorooctane sulfonate (PFOS), phenol, toluene, antimony, barium, boron, silver, thallium, tin, and m-xylene;

- Potential Receptors:
  - a number of sites were noted to have surface water courses, or groundwater SPZ, within the vicinity of fields being spread.

While there were data available on the nutrient content of the sludges, for most sites there was insufficient data on the quality and composition of the receiving soils to run the Smart Form and assess nutrient benefit.

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[7] Maximum permitted annual application rates for both arable soils and grassland: fluoride – 20kg/ha.

Whilst examples of soil analyses and a benefit statement were provided for fields at Site E2, it was unclear whether the treated sludge sampled was going to be spread at either of these locations.

4.7.3　Limitations

The following limitations were noted in completing the risk assessment:

· there were a number of PTE or POP detected which cannot be assessed by the Smart Form and for which the level of risk is therefore currently unknown. These are tabulated below. For these analytes, either specific physio-chemical data were missing from the database used by the Smart Form, or SSV were not available. In addition, it was not possible to assess the benefits and risks associated with nutrients given the limited site and field-specific data characterising soil conditions and cropping. Nutrients, therefore, also appear in Table 4-5;

Table 4-5 - Analytes that could not be Assessed Using the Smart Form

Media	Chemical Group	Chemical Name
Sludge / Ash	Bacteria Suite - Microbiological	Escherichia coli
		Salmonella
		Total Coliforms
	Organo Metals	Dibutyltin
	Suite A – Inorganics	Ammoniacal Nitrogen as N
		Neutralising value
		Nitrogen, Total*
		Phosphate (Bicarbonate Extractable) as mg/l P
		Sulphur*
	Suite A - Metals - (Liquid)	Extractable Calcium (Top Soil)*
		Extractable Magnesium (Top Soil)*
		Extractable Potassium (Top Soil)*
		Extractable Sodium (Top Soil)*
	Suite A - Metals - (Solids)	Aluminium
		Bismuth
		Calcium*
		Iron
		Lithium
		Magnesium*
		Phosphorus*
		Potassium*
		Sodium*
		Strontium
		Tellurium
		Titanium
	Suite A - Polyaromatic Hydrocarbons	Acenaphthene
		Acenaphthylene
		Anthracene
		Benz(a)anthracene
		Benzo(b)fluoranthene
		Benzo(g,h,i)perylene
		Benzo(k)fluoranthene
		Chrysene

Media	Chemical Group	Chemical Name
		Dibenzo(a,h)anthracene
		Fluoranthene
		Fluorene
		Indeno(1,2,3-cd)pyrene
		Phenanthrene
		Pyrene
	Suite B - Miscellaneous Organics	1,2-Bis(pentabromophenyl) ethane
		6:2-PTS 27619-97-2
		Branched PFOS
		Cyclohexane Extractable Matter
		Galoxolide
		Nonylphenol
		PFOS
		PFOS (Perfluoro-1-octanesulfonate) 1763-23-1
		Tris(1-chloro-2-propyl)phosphate
	Suite B - Semi-Volatile Organic Compounds	4-Methylphenol
		bis(2-Ethylhexyl) phthalate[#]
	Suite B - Subcontracted: Organics	Aminomethylphosphonic acid
		Glyphosate
		Triclosan[#]
	Suite B - Volatile Organic Compounds	1,2,4-Trimethylbenzene
		1,3,5-Trimethylbenzene
		Carbon Disulphide
		Propylbenzene

*: Nutrients - not assessed during Phase 2 due to lack of soil and field specific data

#: Listed within Smart Form, but unable to assess due to missing physio-chemical data or screening criteria

· for treated sewage sludge, where site-specific spreading rates were available and used in the Smart Form, risks were flagged for benzo(a)pyrene and the dioxins, furans and dioxin-like PCBs. However, these compounds are not typically analysed in receiving soils, and in the absence of concentrations of these contaminants in the receiving fields, the risk assessment assumed median background soil concentrations from the UK soil and herbage pollutant survey dataset. Whilst this assessment is conservative in the event that actual background concentrations of PTEs and POPs are lower than the median value for the UK dataset, it does flag the potential for these contaminants to pose a risk to human health;

· there were no benefit statements available for the fields spread, or alternative information providing details of the location and quality, of receiving soils or, of the rate that waste would be applied. This meant that the benefits and risks from nutrient application could not be assessed.

These data gaps and the assumptions result in some uncertainty about the overall balance between benefit and risks from waste spreading at these sites. This could be addressed by re-running the Smart Form and revising the assessment in the event that additional data on receiving soils are available. However, the work conducted to date has provided a preliminary assessment of risks to potential receptors from POP and PTE.

4.8   Key Findings

4.8.1   Pig and Poultry Sites

The field audits conducted indicated that for the most part:

- the incinerators were being appropriately located and manged with the operators keeping records of services;

- whilst in the incinerator and ash receptacle, the ash was inaccessible to stock at the site and generally secure;

- other than plastic bags and some plastic ear tags, there was no evidence of co-incineration of other wastes alongside the pig and poultry carcasses;

- the volumes of ash being produced at the site were typically much smaller than the available land bank at each site could receive, assuming spreading at the maximum rate of 150 kg/Ha/yr allowed under the U15, and this was confirmed by the low spreading rates provided by the farmers;

- there was evidence of spreading activities which did not comply with the U15 specifications; namely:

  – direct spreading of ash to land without mixing with slurry;

  – potential export of ash and manure from the place of production to other farms; and

  – spreading to land without a recognised benefitting crop.

With respect to the levels of contaminants present in the ash, a conservative assessment of the potential risks to the soil, human health, and ecological receptors (using assumptions on the composition of the receiving soils, spreading rates and methods of application) did not indicate any risks.

Potential enrichment of naphthalene was identified by the Smart Form as a potential issue; but this reflects the absence of background data for naphthalene in receiving soils rather than an issue with the ash.

Taking into account the above findings, and based on the site visits completed, no significant risks associated with the spreading of pig and poultry ash to agricultural land under a U15 exemption were identified. Operators may benefit from additional guidance and regulatory oversight to ensure that the conditions of the U15 are being followed.

4.8.2   Sludge Sites

The site audits identified the following areas of concern associated with the treatment and storage of sludge at the sites:

- based on observations of the treated waste stockpiles, the mixing of lime with the sludge using a telehandler or shovel loader did not consistently distribute lime evenly through the sludge stockpile;

- in many cases there was insufficient evidence to confirm that the treatment had maintained a pH of greater than 12 for a period of 2 hours or more;

- the frequency and accuracy of the calibration records for the pH meter were incomplete, and in many cases calibration was completed using a single calibration solution;

- limited drainage and retention of runoff from the stockpiles on the treatment pads.

The results of the microbial analysis indicated high concentrations of e-coli and detections of Salmonella identified in the lime treated sludge, illustrating that the lime treatment may not be successfully reducing microbial levels in lime treated sludge. The presence of Salmonella in the treated sludge also meant that this did not meet the definition of enhanced treated sludge.

The assessment indicated potential risks to human health from the following POP: benzo(a)pyrene, dioxins, furans and dioxin-like PCBs, plus PTE manganese.

There were also potential issues with enrichment of a wider range of PTE and POP, which may indicate that long term spreading of sludges at the modelled rates could result in accumulation of these contaminants to levels which may pose a risk.

5.   Summary and Comparison of Analytical Data

This Section presents a summary and comparison of analytical data from the M2L, WEP and CIP studies and other readily available, published information.

There is considerable variability between these studies, both in terms of the specific analytes included and in the format of the data presented in reports. In some cases, only summary statistics (e.g. median, quartiles) were provided rather than the range of detected concentrations (minimum (min.) to maximum (max.)). This has made a standardised comparison of each class of analytes (e.g. PAHs, metals) across the studies difficult. Instead, comparisons have been made where possible. These use a tabular format, rather than a graphical format, due to the limited data for some studies.

5.1   PCDD/PCDF (dioxins and furans)

Polychlorinated dibenzo-p-dioxins (PCDD or dioxins) and polychlorinated dibenzofurans (PCDF or furans) comprise upwards of 200 individual chemicals, formed through incomplete combustion, and as by products during manufacture of chemicals including chlorinated hydrocarbons and pesticides. Some dioxins and furans are carcinogenic and can persist in the environment for years, and were included in the original list of twelve Persistent Organic Pollutants (POPs) by the Stockholm Convention on Persistent Organic Pollutants in 2001 (http://chm.pops.int/, accessed June 2017).

Total PCDD/PCDF concentrations expressed as World Health Organisation (WHO) 2005 Toxic Equivalents (TEQs) are summarised in Table 5-1 below.

Table 5-1 – Total PCDD/PCDF Concentrations Expressed as World Health Organisation (WHO) 2005 Toxic Equivalents (TEQs)

Project	Rigby et al.[8]			M2L2	
	Biosolids	Compost Like Output (CLO)	Poultry Litter Ash (PLA)	Sludge	Ash
Mean (WHO 2005 TEQ), ng/kg	11.5	14.7	6.6	4.24	0.509
Max (WHO 2005 TEQ), ng/kg	12.4	18.2	12.3	15.12	11.89
Range (WHO 2005 TEQ), ng/kg	10.5 – 12.4	11.2 – 18.2	0.91 – 12.3	2.16 - 15.12	0.002 – 11.89
No. samples	2	2	2	24	59

In the M2L2 study, the dioxin compound OCDD was present in different materials in the following ranges:

·   Treated sludge: 187 – 1,170 ng/kg;

·   Ash: 0.31 – 20.9 ng/kg.

This is a broader and slightly lower range of concentrations than the findings of Rigby et al. (2015), which reported OCDD in the range 1,170 – 1,990 ng/kg in two biosolids samples, and lower than the maximum concentrations in the range 6.88 – 182.4 ng/kg detected in two samples of PLA.

Replicating the findings of Rigby et al., OCDD was the dominant congener (in absolute rather than TEQ terms) in M2L2 sludge, although 2,3,7,8-TCDF was the dominant congener in both pig and poultry ash. It is reported that the most common source of 2,3,7,8-TCDF is as a by-product during manufacturing of other chemicals and bleaching of paper pulp (pubchem website, accessed June 2017). The source of the TCDF detected in ash in unclear.

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[8] Rigby H, Dowding A, Fernandes A, Humphries D, Petch RG, Reynolds CK, Rose M, Smith SR. Organic Contaminant Content and Physico-Chemical Characteristics of Waste Materials Recycled in Agriculture. Agriculture. 2015; 5(4):1289-1328.

The concentration of PCDD/PCDF in ash is skewed by the results of three samples, all from a single pig farm (site E6), which had elevated concentrations of PCDD/PCDF (3.7 – 11.89 ng/kg TEQ). All other ash samples had PCDD/PCDF concentrations of < 1.0 ng/kg TEQ. The pig farm at E6 was one of the two farms where plastic ear tags were left in sow carcasses, which were then incinerated. It is not certain to what extent this may have influenced the PCDD/PCDF results.

None of the M2L2 ash samples exceeded the PLA Quality Protocol (QP) threshold concentration of 20 ng/kg (WHO-2005 TEQ) for dioxins. Although the overall mean for the M2L2 ash samples was below the PLA QP threshold concentration of 10 ng/kg (WHO-2005 TEQ) for an average of 10 samples, a sample of pig ash from E6 exceeded this threshold.

No analytical data for dioxin and furan concentrations in wastes analysed as part of the WEP project was available for review.

5.2   PCBs

Polychlorinated biphenyls (PCBs) belong to a broad family of man-made organic chemicals, with varying properties including non-flammability, chemical stability, high boiling point and electrical insulating properties. Because of these properties, PCBs were used in a range of industrial and commercial applications, including:

· electrical, heat transfer and hydraulic equipment;

· plasticizers in paints, plastics and rubber products; and

· pigments, dyes and carbonless copy paper.

These same properties mean PCBs are not readily degraded in natural environments, and have high ecotoxicity. PCBs were one of the twelve original pollutants selected for inclusion by the Stockholm Convention on Persistent Organic Pollutants (POPs) in 2001 (http://chm.pops.int/, accessed June 2017).

The M2L2 samples were analysed for dioxin-like PCB congeners only (the 12 PCB congeners for which the World Health Organisation (WHO) has published toxic equivalents (TEQ)). The WHO list comprises the following PCB congeners:

· PCB 77, 81, 105, 114, 118, 123, 126, 156, 157, 167, 169, 189

Available European guidelines for PCBs in biowaste relate to the International Council for the Exploration of the Seas (ICES) PCBs, which is a group of 7 PCB congeners of lower toxicity. These congeners are different to those analysed in the M2L studies, and it is therefore not possible to directly compare the results of the M2L studies with ICES guideline values. The ICES PCB congeners are listed below;

· PCB 28, 52, 101, 118, 138, 153, 180

The maximum concentration of any PCB congener in the M2L2 samples was 2,440 ng/kg for PCB-118 in a sludge sample from site A2. The same sludge sample also contained the maximum sum (4,179 ng/kg) of the 12 PCB congeners.

The sum of 12 PCB congeners in the various materials was in the following ranges:

· Sludge: 603 to 4,179 ng/kg

· Ash: 3.2 to 131 ng/kg

PCBs are clearly more prevalent in sludge than in pig/poultry ash, which is consistent with the more ubiquitous presence of these compounds in an urban environment relative to a rural, agricultural environment.

Rigby et al. reported PCBs in terms of the WHO_{2005}-TEQ value (for dioxin-like PCBs) and the actual concentrations of the various congeners. Total PCB concentrations detected in M2L2 are summarised alongside the Rigby data in

Table 5-2 below.

Table 5-2 – Comparison of Total PCBs in Sludge, Ash and Stackable Wastes

Project	Rigby et al.			M2L2		M2L1
Waste Type	**Biosolids**	**CLO**	**PLA**	**Sludge**	**Ash**	**All solid samples**
Non ortho-PCB (PCB 77, 81, 126, 169)						
TEQ (ng/kg), range	1.07 – 1.66	0.72 – 0.77	0.03 – 0.36	0.27 – 0.57	0.00004 - 1.9	ND - 33.56
Ortho-PCB						
TEQ (ng/kg), range	0.11 – 0.29~	0.09 – 0.09˜	0.004 – 0.005˜	0.02 – 0.12 [#]	0.00003 – 0.00083 [#]	ND - 3.347 [#]
ICES 7 [+] (µg/kg)	19.3 – 46.8	17.2 – 18.9	0.48 – 0.49	n/a	n/a	n/a

˜ = sum of PCB 18, 28, 31, 47, 49, 51, 52, 99, 101, 105, 114, 118, 123, 128, 138, 153, 156, 157, 167, 180, 189
[#] = sum of PCB 105, 114, 118, 123, 156, 157, 167, 189
[+] = sum of PCB 28, 52, 101, 118, 138, 153, 180
n/a = not applicable
ND = Not detected above analytical laboratory method reporting limit

The findings from each project are summarised below:

· for M2L2, sludge contained higher levels of both non-ortho and ortho PCBs than ash, with PCBs detected in 21 out 45 sludge samples and 14 out of 59 ash samples tested;

· the concentration of non ortho-PCBs in ash is skewed by the results of three samples, all from a single pig farm (E6),which had elevated concentrations of PCB 126, ranging from 0.36 – 1.82 ng/kg TEQ, though it is noted that PCB-126 has a TEQ of 0.1);

· a greater range were detected in M2L1 with up to 33.56 ng/kg TEQ for non ortho-PCB and 3.35 ng/kg TEQ for ortho-PCB;

· the concentrations of non ortho-PCB detected by Rigby et al., are broadly comparable to the range detected in the M2L2 samples.

Considering the concentrations of individual congeners:

· in the M2L1 study, dioxin-like PCBs were detected in 17 out of 20 samples, with a maximum total PCB concentration of 183,040 ng/kg in a sample of de-inked paper (compared to 4,179 ng/kg in 21 out of 45 sludge samples sludge in M2L2). The next highest total PCB concentration was 4,050 ng/kg in a sample of gypsum; and

· in the WEP Biowaste Treatment project (Strand 3), PCBs were detected in 11 out of 33 solid samples, with a maximum total PCB concentration of 238,000 ng/kg in a sample of PAS100 compost, spread directly to land. Six other solid samples had total PCB concentrations exceeding 10,000 ng/kg.

The Environment Agency publication "Soil Guideline Values for dioxins, furans and dioxin-like PCBs in soil (Science Report SC050021, 2009) reports that "PCBs are ubiquitous in urban waste waters and may be found in sewage sludge and sludge-amended soils (Wild et al., 1995; Beck et al., 1996; Stevens et al., 2001). The EA publication referenced previous work by Stevens et al. (2003) which involved analysis of PCBs (ortho PCB congeners) in digested sludge from 14 UK waste water treatment plants: "*The mean PCB content of the mono-ortho dioxin-like PCBs was 12.2 µg kg^{-1} dry weight (DW), with PCB 118 and PCB 123 making up over 80 per cent of the mass.*" The recommended soil guideline value proposed by the EA was 8 µg/kg (for residential and allotments end uses) for total PCDDs, PCDFs and dioxin-like PCBs.

Levels of PCBs in some of the WEP samples are considerably higher than the mean results reported for sludges in previous studies and in the M2L2 study, and higher than the risk-based limits for allotments. A further factor to consider is that, in many cases, the reported detection limits in the WEP study were high (for example, often 20 µg/kg or higher). It is therefore possible that small but significant concentrations of PCBs may be even more widespread.

5.3   PFAS

PFAS is an abbreviation for per- and polyfluoroalkyl substances, one of which is PFOS (perfluorooctane sulfonate) which has attracted considerable, if not the most, attention to date. PFOS has been used globally in many applications, including:

·   electric and electronic parts;

·   fire-fighting foam;

·   photo imaging; and

·   hydraulic fluids and textiles.

PFOA, which has also received more attention, has been mainly used in the production of fluoropolymers used in electronics, textiles and non-stick cookware (Public Health England (PHE), 2009).

PFOS is extremely persistent in the environment, can bioaccumulate, and is included in Annex B of the Stockholm Convention.

In the M2L2 data, PFOS was detected in 18 of 24 samples of treated sludge (Table 5-3). The maximum concentration was 0.0459 mg/kg, and 5 samples had PFOS concentration greater than 0.01 mg/kg. In most cases other PFAS compounds, including PFOA, were not present above detection limits of 0.001mg/kg.

Table 5-3 – Comparison of PFOA and PFOS in UK and European Sludges

	M2L2 (treated sludges only)		**FATE SEES** (Tavazzi et.al.)	
	No of detections / samples analysed	Concentration range (mg/kg)	No of detections / samples analysed	Concentration range (mg/kg)
PFOA	0 / 24	n/a	61 / 61	0. 0012 - 0.0475
PFOS	18 / 24	0.0030 – 0.046	59 / 61	0.0017 – 0.434

The maximum concentration of PFOS of 0.046mg/kg detected in M2L2 is significantly lower than the maximum concentration of PFOS of 0. 434mg/kg detected in European sewage sludges, as reported in the FATE-SEES report (Tavazzi et.al., 2012).

PFAS compounds were not analysed in CIP or the Biowaste Treatment project. Rigby et al. do not report PFAS concentrations but note that PFOS was detected by screening at concentrations > 10 µg/kg (i.e. 0.01 mg/kg) in biosolids and CLO. PFOS and PFOA were not detected in solid waste samples analysed during the M2L1 project.

At the time of completing the review for the M2L2 project (June 2017) UK screening thresholds were not available for PFOS or PFAS so it has not been possible to assess the significance of these concentrations. Rigby et al. note an earlier study (Clark & Smith, 2011) which identified PFOS concentrations of 196 µg/kg (0.2 mg/kg) in biosolids.

5.4   PAHs

PAHs comprise a group several hundred chemically-related, environmentally persistent organic compounds. Most are formed by incomplete combustion of organic materials, and can originate from natural sources (volcanic eruptions and forest fires) and anthropogenic sources (asphalt, coal tars, coal fires, wood burning stoves).

5.4.1   Sum of 4 PAHs

Rigby et al. reported the sum of concentrations of 4 priority PAHs (benz(a)anthracene, chrysene, benzo(b)fluoranthene and benzo(a)pyrene, referred to hereafter as PAH_4), with a maximum concentration of 0.719 mg/kg (Table 5-4).

In the M2L2 study, the PAH_4 concentrations were appreciably lower for pig and poultry ash than for sludge (maximum of 0.8125 mg/kg for ash, and 50.7 mg/kg for sludge). The maximum PAH_4 recorded in ash was from site E4, where the sample was collected by the farmer and provided to AECOM at the farm entrance. The maximum PAH_4 concentration was recorded in sludge from site B2 (50.7 mg/kg) was two orders of magnitude greater than the sum of PAH_4 reported by Rigby et al. The three highest PAH_4 concentrations were all associated with treated sludge from B3; excluding data from this site, the remaining PAH_4 concentrations in treated sludge were in the range of 0.8 to 5 mg/kg.

For the 33 biowaste treatment solid samples submitted for PAH analysis in the WEP, concentrations ranged from non-detect to 0.081mg/kg.

PAH_4 concentrations detected in biosolids analysed during M2L1 ranged from <0.05 to 2 mg/kg, with the PAH_4 concentrations in compost ranging from 0.6 to 22 mg/kg. The highest PAH_4 concentrations of 109 mg/kg were detected in a mixed source, food waste sample. A summary of the PAH_4 concentrations detected in M2L, M2L2 and WEP projects is presented in Table 5-4.

Table 5-4 - Summary of Results for PAH_4 and PAH_{16}

Project		Rigby et al.			M2L2		M2L1	Biowaste
		Biosolids	CLO	PLA	Sludge	Ash	Stackable wastes	All solid samples
PAH_4, mg/kg	Max	0.719	0.563	0.097	50.7	0.8125	109.5	99
	Range	0.414-0.719	0.336-0.563	0.017-0.097	0.799-50.7	ND-0.8125	ND – 109.5	ND - 99
PAH_{16}, mg/kg	Max	n/a	n/a	n/a	171	7.25	647	202
	No. samples > 6 mg/kg	n/a	n/a	n/a	34 (75%)	1 (3%)	3 (9%)	8 (24%)

5.4.2   Sum of 16 PAHs

The proposed EU JRC threshold for biodegradable waste of 6 mg/kg is based on the sum of 16 PAH compounds (see Appendix D.5). In the M2L2 study, of the 45 sludge samples analysed for PAH_{16}, 34 (75%) exceeded this threshold. Only 1 out of 58 ash samples exceeded this threshold. Three sludge samples exceeded the threshold by an order of magnitude or more (i.e. > 60 mg/kg), with the highest concentration being 171 mg/kg.

In the M2L2 study, one or more PAH compounds were detected in the samples collected from 17 of the 20 ash sites, and in the samples collected from all eight of the treated sludge sites.

In the M2L1 study, 32 stackable waste samples were analysed for a suite of PAHs. The majority of samples had detectable concentrations of PAH, with a maximum total PAH_{16} concentration of 647 mg/kg, and a mean total PAH_{16} concentration of 24.8 mg/kg. In liquid (non-stackable) wastes, PAHs were rarely detected, and at individual concentrations lower than 1 mg/l in all cases.

In the biowaste treatment study, PAHs were present in only a very small number of liquid samples. In the solid samples, PAHs were detected in 21 out of 33 samples, with a maximum total PAH of 267 mg/kg, and maximum PAH_4 concentration of 99 mg/kg – these results are from a sample of material used for restoration of a china clay quarry.

Concentrations of individual PAH species detected in sludge and biowaste in M2L2, WEP, Rigby et al., and the FATE SEES project are summarised in Table 5-5 below.

Table 5-5– Comparison of PAH Detections in Sludge and Biowaste

Determinand	Waste Type	Biosolids	Sewage Sludge	Treated Sludge	Solid Biowaste
	Project	Rigby et. al.	FATE SEES (Tavazzi et.al.)	M2L2	Biowaste Treatment
	Units	Range	Range	Range	Range
Acenaphthene	mg/kg			0.0547 - 3.47	0.0065 - 1.59
Acenaphthylene	mg/kg			0.0414 - 0.267	0.0072 - 1.27
Anthracene	mg/kg		ND - 0.724	0.0704 - 7.42	0.0448 - 3.00
Benz(a)anthracene	mg/kg	0.019 - 0.087	ND - 1.833	0.209 - 13.6	0.207 - 21.50
Benzo(a)pyrene	mg/kg	0.157 - 0.176	0.0179 - 1.476	0.218 - 12.6	0.140 - 20.00
Benzo(b)fluoranthene	mg/kg	0.169 - 0.302	ND - 1.919	0.215 - 12.6	0.284 - 27.70
Benzo(e) pyrene	mg/kg		0.0189 - 1.477		0.216 - 14.10
Benzo(g,h,i)perylene	mg/kg		0.0297 - 1.335	0.177 - 9.06	0.138 - 12.80
Benzo(k)fluoranthene	mg/kg		0.0099 - 1.048	0.0978 - 6.13	0.116 - 11.10
Chrysene	mg/kg	0.069 - 0.153	ND - 2.021	0.157 - 12.1	0.249 - 29.50
Coronene	mg/kg		ND - 0.55		0.0392 - 2.260
Dibenzo(a,h)anthracene	mg/kg		ND - 0.548	0.0761 - 2.11	0.0285 - 3.740
Dibenzo(a,e) pyrene	mg/kg		ND - 0.0734		
Dibenzo(a,h) pyrene	mg/kg		ND - 0.433		
Fluoranthene	mg/kg		0.0345 - 3.217	0.421 - 31	0.309 - 30.10
Fluorene	mg/kg			0.0627 - 2.15	0.0207 - 0.369
Indeno (1,2,3-cd)pyrene	mg/kg		0.0242 - 1.401	0.129 - 7.37	0.138 - 14.00
Naphthalene	mg/kg		ND - 0.544	0.0977 - 6.18	0.0201 - 3.64
Phenanthrene	mg/kg		0.0299 - 5.522	0.252 - 27.5	0.0704 - 4.55
Pyrene	mg/kg		0.0472 - 2.637	0.332 - 26.1	0.265 - 19.70

The table illustrates that in general, the maximum concentrations of PAHs detected in treated sludge in M2L2 and biowastes in WEP were generally higher than those reported for European sludges in the FATE SEES project.

Based on the PAH analysis of stackable wastes, pig and poultry ash, treated sludge and biowaste treatment samples completed as part of the M2L and WEP projects, a significant proportion of material applied to land is likely to exceed the proposed EU JRC threshold for PAH of 6 mg/kg

5.5   PBDE

Polybrominated diphenyl ethers (PBDE) were analysed in the M2L2 study. All results were below the detection limit of 0.1 mg/kg. No PBDEs were detected in the screening of the biowaste samples in the WEP project. Rigby et. al. reported PBDE in biosolids, CLO and PLA, but at maximum concentrations of 0.042 mg/kg, i.e. below the M2L2 detection limit. While no PBDE was detected in the M2L2 analysis, the results from Rigby et. al. suggests that PDBE may be present at low concentrations in sludge and potentially other waste streams.

5.6   Pesticides

Analysis of a comprehensive suite of pesticides was completed on treated sludge samples in M2L2, with the suite including aldrin, chlordane, cypermethrin, DDT, dieldrin, endosulfan, endrin, lindane, mirex, pentachlorophenol, permethrin, phorate, telodrin, and toxaphene. Pesticide screening was conducted on samples analysed in M2L1. With the exception of methyl parathion (detected in four paper sludge samples in M2L1 at a maximum concentration of 1.97 mg/kg), no other pesticides were detected above respective reporting limits for stackable wastes.

The WEP study included analysis of a pesticide suite including aldrin, dieldrion, endrin, DDT (and breakdown products DDD and DDE), chlordane, lindane, endosulfan and trichlorobenzene. The results are summarised in Table 5.6 below.

Table 5-6 – Summary of Pesticides Detected in Solid Samples in the Biowaste Treatment Study

Compound	Detections / Samples Analysed	Max. detected concentration (mg/kg)	Mean of detected concentrations (mg/kg)
DDE –pp	6 / 33	0.017	0.012
HCH –gamma (lindane)	2 / 33	0.012	0.01
Chlordane	1 / 33	*0.014*	*0.014*
DDD –op	1 / 33	*0.013*	*0.013*
DDT -op + DDD pp	1 / 33	*0.032*	*0.032*
DDT –pp	1 / 33	*0.006*	*0.006*
Dieldrin	1 / 33	*0.012*	*0.012*

Lindane and DDE were detected in more than one sample analysed in the WEP biowaste treatment study (Table 5-6). Lindane is a broad spectrum insecticide used primarily in seed and wood treatment and in lice treatment shampoos while DDE is primarily a breakdown product of DDT. Both lindane and DDT are listed in the Stockholm Convention as persistent organic pollutants.

Chlordane, dieldrin, DDD and DDT were also identified in a single solid sample in the WEP project, at concentrations close to the reporting limits. These detections all related to a sample biowaste from a recycling plant which received waste primarily from local authority recycling centres.

DDT and diazinon (an insecticide) were detected in leachate and liquor samples generated during biowaste treatment processes sampled as part of the WEP. In addition, heptachlor and methyl parathion were detected in non-stackable/liquid wastes analysed in M2L1 (Table 5-7).

Table 5-7 – Summary of Pesticides Detected in Liquid/Non-Stackable Waste Samples

Project	Compound	Detections / Samples Analysed	Max. detected concentration (μg/L)
Biowaste Treatment	DDT -op	1 / 25	0.286
	Diazinon	1 / 28	0.181
	Heptachlor	1 / 23	2.73
M2L1	Heptachlor	1 / 31	21
	Methyl parathion	2 / 31	52

5.7   Herbicides and Fungicides

A summary of the herbicides and fungicides detected in M2L1, M2L2 and the WEP projects is presented in Table 5-8 below.

Table 5-8 – Summary of Herbicides and Fungicides Detected in Solid / Stackable Waste

Project	Compound	Detections / Samples Analysed	Concentration Range (mg/kg)	Mean of detected concentrations (mg/kg)
M2L2	Aminomethylphosphonic acid (AMPA)	24 / 24	0.37 - 5.6	1.66
	Glyphosate	22 / 22	0.048 - 0.84	0.27
M2L1	Aminomethylphosphonic acid (AMPA)	17 / 23	0.01 - 86.3	5.42
	Glyphosate	16 / 22	0.011 - 0.85	0.19
Biowaste	Hexachlorobenzene	7 / 33	0.0017 - 0.0042	0.002
	Dichlobenil	1 / 33	0.001	0.001

The herbicide glyphosate (and breakdown product AMPA) were routinely detected in soils and wastes in M2L1 and in treated sludges in M2L2. This reflects the widespread use of glyphosate in both agricultural and domestic garden settings.

Other herbicides including pendimethalin, triallate, and trifluralin were also analysed in treated sludge, but none were detected above respective reporting limits.

Common fungicides including chlorothalonil, tecnazene and triadimefon were analysed in treated sludges in M2L2, but were not detected above reporting limits of 1 mg/kg.

Hexachlorobenzene and dichlobenil were detected in solid samples in the WEP biowaste treatment project. Hexachlorobenzene was formerly used as a seed treatment and is banned under the Stockholm Convention, while diclobenil (also known as dichlorobenzonitrile) is no longer approved for use in the EU Pesticides Database (http://ec.europa.eu/food/plant/pesticides/eu-pesticides-database/public/?event=activesubstance.detail&language=EN&selectedID=1210).

Herbicides and fungicides were also detected in liquid / non stackable wastes as shown in Table 5-9 below.

Table 5-9 – Summary of Herbicides and Fungicides Detected in Liquid / Non-Stackable Waste

Project	Compound	Detections / Samples Analysed	Concentration Range (µg/L)	Mean of detected concentrations (µg/L)
M2L1	Aminomethylphosphonic acid (AMPA)	22 / 29	0.85 - 209	6.86
	Glyphosate	21 / 28	0.49 - 150	17.02
Biowaste	Chlorpropham	3 / 28	0.212 - 12.6	4.6
	Dichlobenil	2 / 26	0.0139 – 0.0243	0.0191
	Ethofumesate	3 / 28	0.012 - 0.12	0.053
	Triallate	2 / 26	0.108 – 1.05	0.579
	Napropamide	1 / 29	1800	n/a
	Propyzamide	1 / 29	161	n/a

With the exception of dichlobenil, all of the other herbicides and fungicides detected in liquid and non-stackable wastes are currently licensed for use in the EU.

5.8   Pharmaceuticals and Personal Care Products

The CIP2 study analysed sewage sludges for a range of pharmaceuticals, mostly comprising human medicines. The study concluded that concentrations for all the pharmaceuticals considered were well below the threshold indicative of negligible environmental risk, even when applying the more stringent standard for higher risk pharmaceutical substances.

In M2L1 and M2L2, a number of key pharmaceuticals representing a wider group of chemicals were specifically assessed. These are discussed in more detail below. A number of personal care products were also assessed.

With respect to human medicines, trimethoprim, an antibiotic frequently used in treating water infections (NHS, https://beta.nhs.uk/medicines/trimethoprim) and discharged in urine was analysed as part of Suite B in M2L2. No concentrations greater than the method reporting limits were detected.

The relative ubiquity of triclosan, present in 92% of sludge samples, is noteworthy (see Table 5-11). Triclosan is an antibacterial compound, which has been implicated as a potential risk in relation to antibiotic resistance[9]. In the M2L1 data, triclosan was only detected in a single sample of compost at a concentration of 0.6 mg/kg.

Galaxolide is an aromatic compound frequently used to fragrance personal care product. It was detected in 25% of samples analysed in M2L2 (see Table 5-11). Rigby et al. (2015) detected galaxolide in biosolids, but were not able to quantify levels. This study also recorded concentrations of 0.299 to 0.455 mg/kg (DS) in CLO.

5.9   Phthalates

Phthalates were detected in a high proportion of samples in both M2L1 and M2L2 (Table 5-10).

Table 5-10 - Summary of Phthalates Results

Compound	M2L1			M2L2 (treated sludges)		
	No. samples	No. detected	Max. detected concentration (mg/kg)	No. samples	No. detected	Max. detected concentration (mg/kg)
bis(2-Ethylhexyl) phthalate	32	22	384 (gypsum)	24	14	6.09
Butylbenzyl phthalate	32	7	0.56 (paper sludge)	24	0	n/a
n-Dibutyl phthalate	32	11	9.61 (paper sludge)	24	0	n/a

The detection of phthalates may result from the presence of plastic in the wastes spread, or from their subsequent degradation (as discussed in Section 2.2.5 and Section 3.2.2.9). In M2L1, the most common individual contaminant identified for stackable (solid) wastes was bis(ethylhexyl)phthalate (DEHP). This is commonly found in plasticisers, and its' occurrence was interpreted to be indicative of elevated amounts of plastic particles within the waste stream. Whilst the occurrence and concentrations detected were greater in M2L1, compared to M2L2, the first phase considered a wider range of waste and the highest levels were present in gypsum and paper sludge, and not biosolids.

[9] Carey, D. E., & McNamara, P. J. (2014). The impact of triclosan on the spread of antibiotic resistance in the environment. Frontiers in Microbiology, 5, 780.

5.10   Other Organic Contaminants

5.10.1   Other Organic Contaminants – M2L2

The M2L2 treated sludge samples were analysed for a range of other organic compounds. In the majority of cases, results were below detection limits.

Those organic compounds that were detected are summarised below.

Table 5-11 - Summary of Other Organic Contaminants Results from M2L2

Compound	No. detections	Percentage detections	Max. detected concentration (mg/kg)	Mean concentration (detections only, mg/kg)
4-Methylphenol	24	100%	435	154.1
Aminomethylphosphonic acid (AMPA)	24	100%	5.6	1.7
Glyphosate	22	100%	0.84	0.3
Toluene	22	96%	11.7	4.9
Phenol	22	92%	573	139.9
Triclosan	22	92%	2.05	0.7
1,2,4-Trimethylbenzene	14	61%	3.45	1.7
p/m-Xylene	9	39%	0.615	0.5
Carbon Disulphide	7	30%	0.695	0.5
1,3,5-Trimethylbenzene	6	26%	0.93	0.6
Galaxolide	6	25%	2.1	1.5
Ethylbenzene	4	17%	0.178	0.2
Nonylphenol	3	13%	0.46	0.4
Dibutyltin	2	8%	0.56	0.3
1,2-Bis(pentabromophenyl) ethane	1	4%	0.1	0.1
Propylbenzene	1	4%	0.324	0.3
Tris(1-chloro-2-propyl)phosphate	1	4%	0.1	0.1

5.10.2   Other Organic Contaminants -WEP

The following organic compounds were present at concentrations above the detection level in one or more solid samples in the WEP data.

Table 5-12 - Summary of Other Organic Contaminants – WEP Data

Compound	No. samples	No. detected	Max. detected concentration (µg/kg)	Mean of detected concentrations (µg/kg)
iso-Propyltoluene	30	13	180,000	20,738
Coronene	33	11	2,260	327
1,2,4-Trimethylbenzene	30	10	3,530	385
Ethylbenzene	30	10	3,100	406

Compound	No. samples	No. detected	Max. detected concentration (µg/kg)	Mean of detected concentrations (µg/kg)
Trichloromethane	30	9	45	14
Toluene	30	9	4,010	525
Methyl Chloride	30	8	118	37
Dimethylbenzene : Sum of (1,3- 1,4-)	30	8	1,070	312
Isopropylbenzene	30	8	372	173
Hexachlorobenzene	33	7	4	2
Carbon Disulphide	30	6	469	107
DDE –pp	33	6	17	12
1,2,3-Trimethylbenzene	30	5	8,460	1,741
o-Xylene	30	5	2,350	509
1,4-Dichlorobenzene	30	5	19	7
1-phenylpropane	30	4	431	147
1,2,4-Trichlorobenzene	33	3	21	8
1,3,5-Trimethylbenzene	30	3	246	98
Benzene	30	3	143	50
Styrene	30	3	85	45
1,2,4-Trichlorobenzene	30	2	111	93
1,2-Dichlorobenzene	30	2	71,900	36,022
HCH–gamma (lindane)	33	2	12	10
1-Phenylbutane	30	2	4,260	2,304
Methylpropylbenzene	30	2	738	377
Trichloroethene	30	2	11	8
1,2,3-Trichlorobenzene	*30*	*1*	*213*	*213*
1,2-Dichloroethane	*30*	*1*	*13*	*13*
1,2-Dichloropropane	*30*	*1*	*11*	*11*
Tribromomethane	*30*	*1*	*254*	*254*
Chlordane	*33*	*1*	*14*	*14*
Chlorobenzene	*30*	*1*	*10*	*10*
Chloroethane	*30*	*1*	*10*	*10*
Cyclopenta(cd)pyrene	*33*	*1*	*188*	*188*
DDD –op	*33*	*1*	*13*	*13*
DDT -op + DDD pp	*33*	*1*	*32*	*32*
DDT –pp	*33*	*1*	*6*	*6*
Dibromochloromethane	*30*	*1*	*21*	*21*
Dibromomethane	*30*	*1*	*10*	*10*

Compound	No. samples	No. detected	Max. detected concentration (µg/kg)	Mean of detected concentrations (µg/kg)
Dichlobenil	*33*	*1*	*1*	*1*
Dieldrin	*33*	*1*	*12*	*12*
Ethyl tert-butyl ether	*30*	*1*	*1,210*	*1,210*
Hexachlorobutadiene	*30*	*1*	*62*	*62*
Tetrachloroethylene	*30*	*1*	*116*	*116*

The following organic compounds were present at concentrations above the detection level in one or more liquid samples in the WEP data.

Table 5-13 - Summary of Organic Compounds - WEP Data

Compound	No. samples	No. detected	Max. detected concentration (µg/L)	Mean of detected concentrations (µg/L)
Phenol	29	10	7,020	1,680
Benzyl Alcohol	29	8	309,000	64,660
Di-n-ButylPhthalate	29	8	616	228
3- + 4-Methylphenol	29	5	19,200	4,803
4-methyl-Isopropylbenzene	25	5	23,400	7,220
1,2,4-Trimethylbenzene	25	3	267	164
o-Xylene}	25	3	193	114
Bis(2-chloroisopropyl) ether	29	3	34,000	11,755
Chlorpropham	28	3	13	4.6
Ethofumesate	28	3	120	53
1,2,3-Trimethylbenzene	25	2	108	71
1,3,5-Trimethylbenzene	25	2	130	82
Azobenzene	29	2	182	105
2,6-Dichlorobenzonitrile	25	2	0	0
Diethyl Phthalate	29	2	132	71
Dimethylbenzene : Sum of isomers (1,3- 1,4-)	25	2	200	131
Ethylbenzene	25	2	79	47
n-Nitroso di-n-propylamine	29	2	24,000	13,655
Styrene	25	2	240	189
Toluene	25	2	401	379
Tri-allate	25	2	1	1
1,2-Dichlorobenzene	*25*	*1*	*83*	*83*
1,2-Dinitrobenzene	*29*	*1*	*78*	*78*
1,3-Dinitrobenzene	*29*	*1*	*25*	*25*

Compound	No. samples	No. detected	Max. detected concentration (µg/L)	Mean of detected concentrations (µg/L)
1-Methylnaphthalene	*29*	*1*	*21*	*21*
2,3,5,6-Tetrachloroaniline	*25*	*1*	*0.0128*	*0.0128*
2-Methylnaphthalene	*29*	*1*	*32*	*32*
o-Cresol	*29*	*1*	*1,480*	*1,480*
4-Bromophenyl phenyl ether	*29*	*1*	*32*	*32*
Benzene	*25*	*1*	*117*	*117*
Benzyl butyl phthalate	*29*	*1*	*38*	*38*
Chlorobenzene	*25*	*1*	*58*	*58*
Trichloromethane	*25*	*1*	*1*	*1*
DDT –op	*25*	*1*	*0.286*	*0.286*
Diazinon	*28*	*1*	*0.181*	*0.181*
Dibenzofuran	*29*	*1*	*22*	*22*
Dimethyl phthalate	*29*	*1*	*34*	*34*
Ethyl tert-butyl ether	*25*	*1*	*6*	*6*
Heptachlor	*26*	*1*	*3*	*3*
Isophorone	*29*	*1*	*21*	*21*
Isopropylbenzene	*25*	*1*	*28*	*28*
Methyl tert-butyl ether	*25*	*1*	*15*	*15*
Napropamide	*28*	*1*	*1,800*	*1,800*
1-Phenylbutane	*25*	*1*	*23*	*23*
Nitrobenzene	*29*	*1*	*1,620*	*1,620*
1-phenylpropane	*25*	*1*	*39*	*39*
Propyzamide	*28*	*1*	*161*	*161*
Perchloroethylene	*25*	*1*	*501*	*501*

5.10.3 Other Organic Contaminants – CIP1

The results from sludge analysis carried out under the CIP1 study are reported by Jones et al. (2014)[10]. Organic compounds analysed comprised PAH, pharmaceuticals, BDEs and a limited range of "emerging" organic contaminants. The results are summarised below.

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[10]Vera Jones, Mike Gardner, Brian Ellor, Concentrations of trace substances in sewage sludge from 28 wastewater treatment works in the UK, Chemosphere, Volume 111, September 2014, Pages 478-484

Table 5-14 - Summary of Other Organic Contaminants – CIP1

Compound	Mean concentration (mg/kg)	Median concentration (mg/kg)	75%ile concentration (mg/kg)	Number of WwTW sampled
BDEs				
2,20 ,4,40 -tetrabromodiphenyl ether (BDE-47)	0.023	0.021	0.031	28
2,20 ,4,40 ,5-pentabromodiphenyl ether (BDE-99)	0.032	0.033	0.043	28
2,20 ,4,40 ,6-pentabromodiphenyl ether (BDE-100)	0.007	0.006	0.009	28
2,20 ,4,40 ,5,50 -hexabromodiphenyl ether (BDE-153)	0.006	0.005	0.008	28
2,20 ,4,40 ,5,60 -hexabromodiphenyl ether (BDE-154)	0.005	0.005	0.005	28
'Emerging' and regulated organic substances				
Diethylhexylphthalate (DEHP)	19.0	11.0	30.8	28
Nonylphenol 4-nonylphenol	4.4	3.8	5.8	28
Tributyltin compounds (Tributyltin-cation; TBT)	0.02	0.02	0.02	28
Triclosan	4.9	4.7	7.0	28
Bentazone	0.07	0.02	0.11	28
Bisphenol-A	0.34	0.21	0.56	28
Nonylphenol Monoethoxylate	5.0	6.1	7.1	6
Nonylphenol Diethoxylate	1.1	1.1	1.3	6
Nonylphenol Triethoxylate	176.0#	0.6	0.9	6
PAHs				
Anthracene	0.11	0.10	0.13	28
Fluoranthene	0.70	0.52	0.77	28
Naphthalene	0.43	0.21	0.40	28
Benzo(a)pyrene	0.38	0.32	0.50	28
Benzo(b)fluoranthene	0.38	0.31	0.46	28
Benzo(k)fluoranthene	0.29	0.25	0.38	28
Benzo(g,h,i)perylene	0.33	0.27	0.44	28
Indeno(1,2,3-cd)pyrene	0.32	0.28	0.42	28
Pharmaceuticals				
Diclofenac	0.06	0.07	0.07	7
Ibuprofen	0.27	0.22	0.39	28
Propranolol	0.14	0.12	0.18	28
Erythromycin	0.06	0.05	0.06	28
Ofloxacin	0.22	0.20	0.27	28
Oxytetracycline	7.63	4.00	8.66	28

Compound	Mean concentration (mg/kg)	Median concentration (mg/kg)	75%ile concentration (mg/kg)	Number of WwTW sampled
Fluoxetine	0.13	0.12	0.18	28

this is reported in a separate summary of CIP1 data as 1.8 mg/kg, and hence the reported result is suspect.

BDE was detected in CIP1, but at concentrations below the detection limits achieved in the M2L2 study.

PAH concentrations in CIP1 were considerably lower than those identified in the M2L2 study.

Triclosan concentrations were somewhat higher in CIP1 but of a similar order of magnitude to those identified in the M2L2 study.

5.11   Metals and Fluoride

5.11.1   Metals and Fluoride in Pig and Poultry Ash

A comparison of metals in pig ash, poultry ash and poultry litter ash is presented in Table 5-15 below.

Table 5-15 – Summary of Metals and Fluoride in Pig Ash and Poultry Ash

		Poultry Ash		Pig ash	
		M2L2		M2L2	
Analyte	Units	Detections / samples	Range	Detections / samples	Range
Aluminium	mg/kg	32 / 32	97.7 – 2,540	27 / 27	163 – 6,350
Antimony	mg/kg	18 / 32	0.677 - 36.2	15 / 27	0.622 - 11.1
Arsenic	mg/kg	2 / 32	0.624 - 1.09	3 / 27	0.661 - 0.95
Barium	mg/kg	32 / 32	29.1 - 147	27 / 27	18.2 - 299
Beryllium	mg/kg	20 / 32	0.0153 - 0.0836	19 / 27	0.0115 - 0.13
Bismuth	mg/kg	3 / 32	1.07 - 4.17	2 / 27	1.1 - 1.77
Boron	mg/kg	32 / 32	5.81 - 25.3	27 / 27	2.09 - 9.37
Cadmium	mg/kg	4 / 32	0.155 - 0.331	0 / 27	n/a
Calcium	mg/kg	32 / 32	543 – 399,000	27 / 27	182,000 – 415,000
Chromium	mg/kg	32 / 32	4.22 - 258	27 / 27	3.51 - 58.8
Cobalt	mg/kg	29 / 32	0.169 - 2.95	23 / 27	0.135 - 1.44
Copper	mg/kg	32 / 32	20.7 - 1690	27 / 27	12.8 - 303
Iron	mg/kg	23 / 29	1,120 – 20,100	24 / 27	1090 - 6920
Lead	mg/kg	21 / 32	1.21 - 705	19 / 27	0.718 - 147
Lithium	mg/kg	19 / 32	1.12 - 2.78	24 / 27	1.02 - 4.11
Magnesium	mg/kg	32 / 32	790 – 12,500	27 / 27	5,610 – 14,100
Manganese	mg/kg	32 / 32	62.9 - 293	27 / 27	11.2 - 342
Mercury	mg/kg	0 / 32	n/a	3 / 27	0.475 - 0.554
Molybdenum	mg/kg	32 / 32	1.61 - 14.9	27 / 27	0.299 - 2.96
Nickel	mg/kg	32 / 32	1.09 - 457	27 / 27	0.769 - 32.3

Analyte	Units	Poultry Ash M2L2		Pig ash M2L2	
		Detections / samples	Range	Detections / samples	Range
Phosphorus	mg/kg	31 / 31	806 – 208,000	27 / 27	112,000 – 220,000
Potassium	mg/kg	32 / 32	1,100 – 81,800	27 / 27	10,500 – 79,600
Selenium	mg/kg	0 / 32	–n/a	0 / 27	n/a
Silver	mg/kg	0 / 32	–n/a	0 / 27	n/a
Sodium	mg/kg	32 / 32	54.8 – 66,300	27 / 27	15,200 – 54,100
Strontium	mg/kg	32 / 32	80 - 159	27 / 27	52.8 - 285
Tellurium	mg/kg	0 / 32	–n/a	0 / 27	–n/a
Thallium	mg/kg	0 / 32	–n/a	0 / 27	n/a
Tin	mg/kg	9 / 32	0.666 - 5.22	5 / 27	0.451 - 6.16
Titanium	mg/kg	32 / 32	1.71 - 601	27 / 27	12.2 - 482
Vanadium	mg/kg	32 / 32	0.489 - 3.78	27 / 27	0.4 - 4.03
Zinc	mg/kg	32 / 32	359 – 1,760	27 / 27	153 – 2,200
Fluoride	mg/kg	27/26	80.2 - 787	27/23	82.5 - 786
Fluoride, acid soluble	mg/kg	4/4	148 - 286		

Comparing the pig and poultry ash, for the most part, the concentration ranges of metals detected in the ash were in the same order of magnitude, with the following exceptions:

· concentrations of cadmium were detected in poultry ash, while no cadmium was detected in pig ash;

· mercury was detected in pig ash but not poultry ash;

· maximum concentrations of chromium, copper, iron, molybdenum, and nickel were an order of magnitude higher in poultry ash compared with the maximums in pig ash.

These trends likely reflect the presence of impurities within feed and vaccinations.

The current limits for poultry litter ash quality protocol are presented in Appendix D3. While not directly applicable to the poultry ash (as this is spread under U15 exemption and is not compatible with quality protocol), the screening can provide a useful guide as to the potential contaminants within the poultry ash. The following observations can be made from screening of the poultry ash data against the limits:

· maximum concentrations of arsenic, cadmium, cobalt, mercury, manganese, molybdenum, selenium, vanadium and zinc were lower than the respective limits for poultry litter;

· maximum concentrations for the following exceeded the respective limits:

– chromium (258mg/kg versus a limit of 31mg/kg);

– copper (1,690mg/kg versus a limit of 596mg/kg);

– nickel (457 mg/kg versus a limit of 24mg/kg); and

– lead (705mg/kg versus a limit of 244mg/kg).

The reason for the elevated concentrations of chromium, copper, lead and nickel is not immediately obvious, and could reflect trace metals within feed, from veterinary treatments, or co-incineration of other wastes.

For comparison, the ranges of selected metals detected in fly ash and bottom ash during production of poultry litter ash (WRAP, 2011) are presented in Table 5-16 below.

Table 5-16 - Comparison of Metals Results in Poultry Litter Ash

Determinand	Units	Poultry Litter Ash*	Poultry Litter Ash*	Poultry Litter Ash*
		Bottom Ash	Fly Ash	Rigby et. al.
		Range	Range	Range
Arsenic	mg/kg	<2 - 4	<2 - 20	3.99 - 12.2
Boron	mg/kg	70 - 200	70 - 230	-
Cadmium	mg/kg	<1 - <1	1 - 4	0.72 - 1.56
Calcium	mg/kg	176,000 – 320,000	24,000 – 171,000	-
Chromium	mg/kg	7 - 50	10 - 35	11 - 31
Cobalt	mg/kg	4 - 11	<2 - 10	-
Copper	mg/kg	30 - 790	185 - 670	310 - 324
Iron	mg/kg	2,500 – 7,400	2200 – 3,900	-
Lead	mg/kg	<1 - 28	11 - 112	14.5 - 186
Magnesium	mg/kg	4700 - 41000	16,000 – 75,000	-
Manganese	mg/kg	1,100 – 3,500	1320 – 2,700	-
Mercury	mg/kg	<0.5 - <1	<0.5 - <1	-
Molybdenum	mg/kg	9 - 40	21 - 52	-
Nickel	mg/kg	<1 - 36	8.6 - 40	12.1 - 16.8
Selenium	mg/kg	<0.2 - 4	<2 - 10	3.68 - 4.77
Sodium	mg/kg	15,000 – 26,000	19,000 – 196,000	-
Vanadium	mg/kg	10 - 12	-	-
Zinc	mg/kg	180 – 1,500	890 – 4,550	1,390 – 1,670

*While these are not directly comparable with the poultry ash results because of the inclusion of the litter and the higher incineration temperatures involved, the results indicate the variation between the metals present in the heavier bottom ash removed from the base of the incinerator and the fly ash removed from the bag filters.

5.11.2   Metals and Fluoride in Biosolids and Sludges

A comparison of the ranges of metal concentrations detected in biosolids (M2L Phase 1), and untreated sludge, treated sludge and lime sampled during Phase 2 is presented in Table 5-17 below. The comparison of fluoride results is presented towards the end of this section.

The following trends are evident from the comparison:

· concentrations of metals in lime are generally much lower than those already present in the untreated sludge;

· concentrations are broadly comparable in the untreated sludge and the treated sludge. This, along with the data for lime, does not indicate addition of metals to the sludge by the lime treatment process. The exception to this, understandably, is calcium;

- concentrations across the biosolids, untreated and treated sludge are all broadly similar; and

- no silver was detected above method reporting limits in any of the samples analysed.

A copy of the current SUiAR limits for PTEs is presented in Appendix D.5. These limits are for the final soil concentrations following spreading and incorporation of the sludge. However, the following conclusions can be drawn from screening of the maximum concentrations in Table 5-17, directly against the PTE limits:

- maximum concentrations of the following PTEs in untreated and treated sludge were less than the respective limits:

  – arsenic;

  – cadmium;

  – chromium;

  – lead; and

  – nickel.

- maximum concentrations of the following PTEs in untreated and treated sludge exceeded at least one of the PTE limits:

  – copper;

  – mercury;

  – molybdenum; and

  – zinc.

While this comparison does not consider the final soil concentrations following spreading, it does give an indication of which PTEs present in treated sludge may pose the highest risk to receiving soils. This, however, would be subject to the spreading rate of the treated sludge, the existing concentration in the receiving soil and the final concentration achieved after spreading. In addition, this assessment was based on the limited suite of metals included in the SUiAR limits.

The risk assessment reported in Section 4 did consider a wider range of analytes including metals not covered by the SUiAR limits. This did not indicate a risk from these additional metals to human health or ecological receptors with the exception of manganese at site A2. This assessment was, however, based on assumed soil chemistry, no data being available for the receiving fields. The assessment did indicate a potential issue with long-term enrichment from spreading of lime treated sludge for antimony, barium, boron, thallium and tin.

Table 5-17 - Comparison of Metal Concentrations

Waste Type		Biosolids		Untreated Sludge		Lime		Treated Sludge	
Project		M2L1		M2L2		M2L2		M2L2	
Determinand	Units	Detections / samples	Range	Detections / samples	Range	Detections / samples	Range	Detections / samples	Range
Aluminium	mg/kg	4 / 4	4100 – 15,800	24 / 24	4,020 – 15,600	7 / 7	470 - 851	24 / 24	3,710 – 15,700
Antimony	mg/kg	4 / 3	1.51 - 2.27	24 / 24	4.53 - 7.01	7 / 1	1.17 - 1.17	24 / 21	2.95 - 22.8
Arsenic	mg/kg	4 / 3	5.86 - 17.2	24 / 24	2.9 - 7.51	7 / 1	0.68 - 0.68	24 / 21	2.48 - 6.2
Barium	mg/kg	4 / 4	110 - 486	24 / 24	139 - 315	7 / 7	5.57 - 11	24 / 24	140 - 277
Beryllium	mg/kg	4 / 4	0.133 - 1.05	24 / 24	0.239 - 0.753	7 / 6	0.0525 - 0.0978	24 / 21	0.132 - 0.603
Bismuth	mg/kg	4 / 4	1.28 - 7.45	24 / 24	1.66 - 118	7 / 0	0 - 0	24 / 24	1.98 - 8.88
Boron	mg/kg	4 / 4	13.6 - 18.5	24 / 24	6.94 - 17.7	7 / 7	1.23 - 2.81	24 / 24	5.51 - 21.5
Cadmium	mg/kg	4 / 4	0.485 - 1.72	24 / 24	0.485 - 0.758	7 / 7	0.0625 - 0.586	24 / 23	0.0318 - 0.775
Calcium	mg/kg	4 / 4	24,300 – 71,700	24 / 24	14,600 – 72,600	6 / 6	493,000 – 755,000	24 / 24	64,200 – 219,000
Chromium	mg/kg	4 / 4	12.7 - 21.4	24 / 24	16.7 - 32.8	7 / 5	3.93 - 5.96	24 / 24	13.7 - 39.2
Cobalt	mg/kg	4 / 4	3.31 - 9.39	24 / 24	2.51 - 5.01	7 / 6	0.351 - 0.607	24 / 24	2.12 - 5.4
Copper	mg/kg	4 / 4	33.8 - 223	24 / 24	118 - 263	7 / 5	1.5 - 3.74	24 / 24	65.4 - 193
Iron	mg/kg	4 / 4	8,120 – 33,200	24 / 24	10,800 – 40,100	7 / 4	1,520 – 2,970	24 / 24	11,000 – 29,600
Lead	mg/kg	4 / 4	46.2 - 143	24 / 24	40 - 132	7 / 1	7.38 - 7.38	24 / 24	34.1 - 104
Lithium	mg/kg	4 / 4	4.12 - 39.3	24 / 0	0 - 0	7 / 6	1.42 - 3.56	24 / 1	1.57 - 1.57
Magnesium	mg/kg	4 / 4	2,260 – 8,900	24 / 24	1680 - 4660	6 / 6	1,080 – 1,740	24 / 24	1680 - 2790
Manganese	mg/kg	4 / 4	245 - 678	24 / 24	150 - 859	7 / 7	80.9 - 392	24 / 24	186 - 690
Mercury	mg/kg	4 / 1	0.237 - 0.237	24 / 12	0.274 - 2.02	7 / 0	0 - 0	24 / 10	0.151 - 4.15
Molybdenum	mg/kg	4 / 4	1.24 - 4.81	24 / 24	2.56 - 5.18	7 / 5	0.116 - 0.354	24 / 24	2.01 - 4.77
Nickel	mg/kg	4 / 4	9.61 - 23.3	24 / 24	13.7 - 22.1	7 / 7	1.39 - 3.36	24 / 24	10.5 - 19.2

Waste Type		Biosolids		Untreated Sludge		Lime		Treated Sludge	
Phosphorus	mg/kg	4 / 4	696 – 25,300	24 / 24	7,870 – 22,800	7 / 7	12.1 - 321	24 / 24	1,290 – 18,400
Potassium	mg/kg	4 / 4	1,720 – 7,970	24 / 24	1,000 – 4,310	6 / 6	166 - 496	24 / 24	1070 - 2460
Selenium	mg/kg	4 / 0	0 - 0	24 / 24	1.76 - 4.21	7 / 0	0 - 0	24 / 17	1.02 - 3.45
Silver	mg/kg	4 / 0	0 - 0	24 / 0	0 - 0	7 / 0	0 - 0	24 / 0	0 - 0
Sodium	mg/kg	4 / 4	306 – 2,480	24 / 24	344 – 2,920	6 / 6	78.6 – 1,780	24 / 24	360 - 1240
Strontium	mg/kg	4 / 4	66.8 - 126	24 / 24	41 - 155	7 / 7	276 - 846	24 / 24	78.5 - 207
Tellurium	mg/kg	4 / 2	2.36 - 2.56	24 / 1	1.28 - 1.28	7 / 2	1.02 - 1.3	24 / 2	1.05 - 1.29
Thallium	mg/kg	4 / 0	0 - 0	24 / 1	0.888 - 0.888	7 / 1	0.761 - 0.761	24 / 0	0 - 0
Tin	mg/kg	4 / 4	7.73 - 31.7	24 / 24	19.8 - 54.1	7 / 0	0 - 0	24 / 24	15.4 - 37.1
Titanium	mg/kg	4 / 4	42 - 120	24 / 24	8.29 - 97.7	6 / 6	1.5 - 19.2	24 / 24	9.17 - 84.7
Vanadium	mg/kg	4 / 4	10.1 - 30	24 / 24	10.1 - 27.7	7 / 7	1 - 6.05	24 / 24	8.62 - 21.6
Zinc	mg/kg	4 / 4	217 - 411	24 / 24	308 - 624	7 / 7	3.04 - 16.3	24 / 24	226 - 468

Concentrations of metals detected in sludge and biowaste in M2L2, WEP, Rigby et al., and the FATE SEES project are summarised in Table 5-12 below.

Table 5-18 - Comparison of Metals in Sludge and Biowaste

Waste Type	Biosolids	Biosolids	Sewage Sludge	Treated Sludge
Project	Rigby et. al.	Biowaste	FATE SEES (Tavazzi et.al.)	M2L2
Determinand Units	Range	Range	Range	Range
Aluminium mg/kg		<50 – 90,500	1,000 – 60,000	3,710 – 15,700
Antimony mg/kg		<1 - 163	<DL - 53.6	2.95 - 22.8
Arsenic mg/kg	4.06 - 8.49	<0.5 - 43.9	<DL - 56.1	2.48 - 6.2
Barium mg/kg		<0.5 - 432	41.5 - 580	140 - 277
Boron mg/kg	25.7 - 62.8	<1 - 226		5.51 - 21.5
Cadmium mg/kg	1.15 - 2.34	<0.2 - 1.98	<DL - 5.1	0.0318 - 0.775
Calcium mg/kg	41,400 – 48,100	<60 – 189,000		64,200 – 219,000
Chromium mg/kg	42.7 - 213	<0.5 - 225	10.8 - 1542	13.7 - 39.2
Cobalt mg/kg		<0.1 - 13.8	1.5 - 16.7	2.12 - 5.4
Copper mg/kg	430 - 446	<1 - 230	27.3 - 578	65.4 - 193
Iron mg/kg	8,240 – 42,500	<200 – 41,100	2,000 – 149,000	11,000 – 29,600
Lead mg/kg	92.6 - 107	<1 - 307	4 - 430	34.1 - 104
Lithium mg/kg		<1 - 65.6		1.57 - 1.57
Magnesium mg/kg	3,650 – 5,940	<20 – 15,500	100 – 22,400	1,680 – 2,790
Manganese mg/kg	357 - 783	<2 - 843	75.2 - 960	186 - 690
Mercury mg/kg	0.81 - 1.12	<0.1 - 6.12	0.1 - 1.1	0.151 - 4.15
Molybdenum mg/kg	8.59 - 20.8	<1 – 19,400	1.7 - 12.5	2.01 - 4.77
Nickel mg/kg	30.5 - 127	0.692 – 3,970	8.6 - 310	10.5 - 19.2
Phosphorus mg/kg	21,300 – 30,000	<10 – 62,000	10,000 – 56,000	1,290 – 18,400
Potassium mg/kg	1,330 – 2,230	<50 – 33,000	1,000 – 26,000	1,070 – 2,460
Selenium mg/kg	3.82 - 4.69	<1 - 2.24		1.02 - 3.45
Silver mg/kg		<1 - 3.53	<DL - 14.7	0 - 0
Titanium mg/kg		<3 - 884	65.2 - 1071	9.17 - 84.7
Vanadium mg/kg		<0.1 - 53	2.3 - 135	8.62 - 21.6
Zinc mg/kg	739 – 1,930	<2 - 1150	200 – 1,200	226 - 468

A number of metals were detected in the Rigby and FATE SEES projects at concentrations one to two orders of magnitude greater than those detected in the M2L2 study. These were:

·   chromium;

·   iron;

·   magnesium;

·   molybdenum;

- potassium;

- titanium; and

- zinc.

The cause of these higher levels, and the extent to which they may reflect inputs and treatment methods, is not known. The other metals were detected at comparable levels across the three studies.

Direct comparison of fluoride across the different studies was complicated by the different analytical methodologies employed. Both acid and water based extractions were used, the former noted to potentially give more elevated concentrations than the latter. In summary, detected fluoride concentrations were:

- M2L2, fluoride (acid soluble) in treated sludge: 308 – 4,780 mg/kg;

- M2L1, fluoride (2:1, water soluble) in solid wastes: 1.01 – 789 mg/kg;

- Biowaste treatment, fluoride (leachable): 0.53 – 41.7 mg/kg; and

- Rigby et al. (2015), fluoride (100:1 H_2SO_4) in biosolids: 151 – 456 mg/kg.

Metals were also tested as part of the CIP projects (fluoride was not tested). A copy of the full dataset was not available and so the range of metals detected in the project was not available. However, the datasets did include mean concentrations for each of the four sampling points (A, B, C, and D).

Table 5-19 - Comparison of Sludge Sampling Points

CIP2 Sampling point	Description	Materials to Land Phase II Equivalent
A	Immediately upstream of treatment	
B	Immediately downstream of treatment	
C	Sludge cake immediately downstream of dewatering	Untreated Sludge
D	Return liquors from dewatering (mg/kg)	
D2	Return liquors from dewatering (µg/l)	
Limed Sludge	Final product sampling point from Lime Treatment sites.	Treated Sludge

Using the range of means detected across the 10 samples, AECOM have produced the following table comparing metals in untreated sludge sampled in M2L2 and CIP2.

Table 5-20 - Summary of CIP2 Results Compared to M2L2 Results for Metals Analysed in Both Projects

Sampling point	mg/kg	Cadmium	Chromium	Copper	Iron	Lead	Mercury	Nickel	Zinc
CIP 2 "Point C" mean*	Min	0.54	22.04	93.37	5,489	38.97	0.49	11.69	333.4
	Max	2.14	85.64	666.2	68,200	139	1.5	44.03	1,039.1
M2L2 Untreated Sludge mean*	Min	0.485	16.7	118	10,800	40	0.274	13.7	308
	Max	0.758	32.8	263	40,100	132	2.02	22.1	624
CIP 2 "Limed Sludge" mean*	Min	0.45	17.27	81.84	5,109	29.94	0.42	10.14	263.6
	Max	0.58	88.36	273.5	37,486	39.31	1.85	10.28	395.29
M2L2 Treated Sludge	Min	0.0318	13.7	65.4	11,000	34.1	0.151	10.5	226

Sampling point	mg/kg	Cadmium	Chromium	Copper	Iron	Lead	Mercury	Nickel	Zinc
mean*									
	Max	0.775	39.2	193	29,600	104	4.15	19.2	468
Sludge Directive[1] - lower		20		1,000		750	16	300	2,500
Sludge Directive[1] - upper		40		1,750		1200	25	400	4,000
Working draft - revision[2]		10	1,000			500	10	300	2,500

* The mean of the results from all the samples collected at each subject site is used.

[1] European Commission (1986) - Sludge Directive (86/278/EEC);

[2] European Commission (2011) Working document on sludge and biowaste. 21/09/2011.

The following conclusions can be drawn:

· the overall levels of metals detected in M2L2 are broadly similar to those detected in CIP2, which provides additional confidence in the range of metals present in sludges;

· in general (and based only on the means) the variability of the untreated sludge tested at the point of production is higher than the variability detected at the farms prior to treatment. This could reflect increased homogenisation through the additional handling steps involved in the untreated sludge sampled in M2L2; and

· none of the means exceed the respective proposed Sludge Directive lower limits.

6.   Review of Landspreading Risks

The review of the risks associated with landspreading is presented in below. This addresses key themes in the form of questions and responses, which draw on the data collected across the Waste Enforcement Program (WEP), including Materials to Land (M2L), and Chemical Investigation Program (CIP). These themes are:

·   contaminants of concern in waste;

·   contaminants of concern entering biotreatment or applied to land;

·   persistence and build-up of contaminants of concern in soil;

·   risks to controlled waters; and

·   compliance / non-compliance.

In assessing the potential risks associated with landspreading based on data from the WEP and CIP it is important to understand the limitations of each component of the studies and how these impact on the overall conclusions which can be drawn from review of the reports. A discussion on the limitations is presented in Section 6.1, below. The WEP comprises M2L1, M2L2, Sampling Wastes at Landfills and Deposit For Recovery (DfR) sites, plus Biowaste Treatment, as described in Section 3.

6.1   Constraints and Limitations of Existing Data

6.1.1   Inappropriate Waste Entering Biowaste Treatment

6.1.1.1   Strand 1 – Waste Types

The Rapid Evidence Assessments were carried out for four sectors, however, the only wastes from these industries reported to be spread directly to land were wastewater treatment works sludge and dust from the wool scouring sector; and this sector only comprises two significant operators in West Yorkshire. Information about whether and how other wastes may be applied to land via composting and AD was very limited. With the exception of the wool scouring report, sampling and analysis was not carried out: although the REA process identified some existing analytical data, this was often noted to be of limited applicability.

The REA process did, however, highlight the relative lack of detailed quantitative data on waste streams from the industries studied. If this is replicated across other industries, it indicates a potentially more widespread lack of knowledge within the industry and regulators of the actual composition of waste that ends up entering the biowaste treatment system.

6.1.1.2   Strand 2 – Waste Producers and Strand 3 – Biowaste Treatment Sites

These two strands included sampling and analysis for a wide range of potential contaminants, both inorganic and organic. Samples were taken from a wide range of waste producers and biowaste treatment sites. The organic contaminants analysed for included many of the priority pollutants that were also included in the Materials to Land study, such as PAHs and PCBs, as well as a range of emerging contaminants of concern. A wide range of waste types were sampled at different locations.

6.1.1.3   Strand 4 – Sewage Treatment Works Desktop Audits

This strand did not include any sampling or analysis. Although it highlighted several potential issues in terms of the traceability of material entering the biowaste treatment system, and how WwTWs are permitted, it does not provide any quantitative data on which to assess the contaminants which are present in sludge.

6.1.2   Deposit for Recovery

The deposit for recovery project provided quantitative data on material being landspread on land for recovery. However, it focussed primarily on those potential contaminants currently listed in the Waste

Acceptance Criteria (WAC) for inert waste plus some additional inorganic substances. It therefore did not provide information on the presence of emerging organic contaminants in this material.

6.1.3   CIP1

The CIP1 sludge analysis was carried out on samples of sludge from different stages of the sewage treatment process, prior to treatment, and was intended primarily to investigate the performance of the wastewater treatment system, rather than the quality of the resulting sludge in the context of its application to land. Although the CIP1 researchers did compare sludge data against land application criteria, they explicitly noted that it was not possible to assess compliance with regards to sludge concentration thresholds.

6.1.4   CIP2

The stated objectives of the CIP2 study included assessing trace substances in sludge cake with regards to the existing Sludge Directive thresholds and other proposed standards, and examining trace substances predicted soil concentrations after application of sludge to land with regards to the PNECs. However, the suite of contaminants analysed in CIP2 was relatively limited, particularly for organic substances. The suite included a wide range of pharmaceutical contaminants, but no other organics, for example no PAH, PCB or dioxins. Although the CIP2 study sampled sludge from several points in the WwTW, the sampling points did not include the point of application of sludge to land.

6.1.5   M2L1

A number of limitations were experienced with the M2L1 project. The first was the timing; the project was carried out in October through February, and missed one of the key autumn spreading windows in September. While receiving soils were sampled where possible, AECOM was unable to sample wastes at many of the farms (as these had already been spread), and therefore unable to confirm that the composition of the wastes spread matched the analysis provided with the deployment application.

A further limitation was the types of farms selected. To avoid conflict, the farms selected (with the exception of one instance) did not include any farms which were under investigation by the EA. This potentially excluded some of the sites where poor spreading practices or spreading of wastes not authorised under the deployment had impacted the quality of the receiving soils. Without including examples of these sites in the wider dataset, it could be argued that the data obtained was reflective of the best case examples, excluding the worst examples, and presenting a picture which was better and not wholly representative.

A final limitation was the wastes sampled. Because the deployments only covered wastes spread under SR2010 No.4 and SR2010 No.5, it was not possible to include many examples of wastes spread under exemptions. Specifically, examples of sewage sludge spread under SUiAR, and spreading of composts and anaerobic digestates meeting end of waste quality protocols PAS100 and PAS110 were not widely assessed.

6.1.6   M2L2

The key limitation with respect to the M2L2 was the absence of soil sampling. Without site-specific soil information (specifically relating to receiving soils for the ash and sludge) it was not possible to definitively identify whether the continued spreading of ash and sludge over successive years to the same receiving fields was resulting in accumulation of contamination within the soils.

The highly alkaline nature of the sludges posed problems with the subsequent analysis and while a large number of contaminants were tested, the reporting limits for some of the contaminants could not match the lower limits achieved for other studies where the sludges had not been recently treated with lime.

6.2 Identification and Categorisation of Potential Risks to Human Health, Environment and Agronomy

6.2.1 Potential Risks

Risks to human health or environmental receptors as a result of waste material applied to land can be categorised as:

· contamination of soil by substances harmful to human health, crops or livestock;

· contamination of groundwater by substances harmful to human health or ecological receptors;

· contamination of surface water by substances harmful to human health or ecological receptors;

· contamination of the food chain by substances harmful to human or animal health; or

· reduction in the agricultural productivity of land.

6.2.2 Potentially Toxic Elements (PTE)

At the most basic level, potential risks to human health, crops and livestock for the most common contaminants are assessed by screening receiving soil concentrations against permissible PTE levels presented in the SUiAR. Where PTE limits are exceeded then a potential risk to the agricultural environment is considered to be present.

The PTE limits in SUiAR are also considered to be protective of risks to controlled waters. Potential risks to controlled waters from nutrients are controlled through limiting inputs of beneficial nutrients (nitrogen, phosphate, potassium, and magnesium) to levels that match what the receiving crop requires, taking into account the levels of nutrients already in the soil. The level of nutrients is assessed using an agricultural benefit statement, based on data provided in RB209, the Fertiliser Manual.

For areas of the country with surface water and groundwater bodies which are more sensitive to nutrient pollution, additional rules are in place regarding spreading of waste in NVZs and Groundwater Safeguard Zones.

However, a significant limitation in solely relying on using PTE limits to assess risk is that these were originally defined in the 1980s based on the identified contaminants of concern and risk assessment methodology available at the time. With the decline in heavy industry, the increasing proportion of urban and runoff sources contributing to urban wastewater and the identification of "emerging toxics" in waste streams, the current PTE suite does not encompass all of the potential contaminants potentially present in wastes spread to land.

The requirements for characterisation of the waste include a stipulation that sufficient testing of potential contaminants is conducted to adequately identify the risks, though in practice (based on the deployment reviews conducted in M2L Phase 1), it is rare that additional testing beyond the basic PTE suite is conducted.

A further limitation is that for many of the emerging toxics, not enough is understood about the toxicity and behaviour of these contaminants in the environment to derive suitable risk assessment criteria which are protective of human health, crops, livestock, controlled waters, and the wider environment.

The EA has developed a revised risk assessment methodology WALTER, which is incorporated into the Smart Form. WALTER incorporates the latest toxicological data for a wide range of contaminants, including PTEs, PAHs, dioxins and furans, and some other emerging toxics, to enable assessment of potential risks to human health via the food chain. Equally, the EA has developed a series of screening values (SSVs) adopted to "*afford a level of protection to terrestrial species and critical ecological functions*" (EA, 2004).

6.3   Contaminants of Concern in Waste

6.3.1   Which Contaminants are Present in Waste and Materials That are Recovered by Application to Land?

The contaminants present in materials applied to land can be broadly categorised as:

·   potentially toxic elements (PTEs), predominantly metals, which have long been recognised as hazards and which are typically included in the thresholds for compost and sludge;

·   other inorganic compounds (e.g. various anions and nutrients) which may affect soil quality or agricultural productivity, or which may affect biological processes. Some of these are included in the regulatory thresholds, or are covered by guidance such as the Jacobs Framework (which outlines the methodology for assessing the suitability of bespoke wastes for biological treatment);

·   organic contaminants, many of which are persistent in the environment and some of which may bioaccumulate. Some of these chemicals are widely recognised as hazards (e.g. dioxins and PAHs) and are often analysed for in wastes, although are not included in the thresholds for compost, digestate and sludge. Others, such as PFAS and pharmaceutical residues, are not routinely analysed and do not have well-established thresholds;

·   physical contaminants such as glass and plastics, which may pose health and safety risks, and in the case of plastics and microplastics release chemicals of concern upon degradation and breakdown; and

·   asbestos, the health risks for which are well known.

6.3.1.1   Potentially Toxic Elements

PTEs are ubiquitous in materials applied to land, and also in soils – these elements typically occur in nature, and the Soil and Herbage Survey provides information on background concentrations in the UK.

6.3.1.2   Other Inorganic Compounds

The other inorganic compounds are also widespread in the environment, and in materials ultimately applied to land. Indeed, the presence of many of these compounds is desirable within certain limits (as in the case of nutrients).

6.3.1.3   Organic Contaminants

The M2L, WEP and CIP studies have all shown that organic compounds are present in many of the materials that are ultimately applied to land, and in many cases these are of anthropogenic origin. The diversity of materials and their sources of origin makes it difficult to make definitive assessments at this stage of how these compounds find their way into certain materials. Some (such as PAHs and PCBs) seem to be ubiquitous, albeit at usually low concentrations. Others are present in a small number of samples, but may be an issue in materials arising from specific sources (e.g. chlorinated solvents). Identifying the presence of organic compounds is also dependent on the detection levels that laboratories are able to achieve. It is possible that, as laboratory techniques improve over time and detection levels reduce, more compounds may be detected. The absence of regulatory thresholds for many compounds means that it is difficult to determine whether non-detects (at current detection levels) are actually indicative of negligible risk.

It is also worth noting that the relative half-life of the compounds when assessing risk is important. For example, volatile aromatic compounds (e.g. toluene) may be present in waste at low levels but are anticipated to break down relatively quickly in soil, whereas other compounds such as PCBs, PBDEs, PFOS, dioxins and furans have very long half-lives in soil and can last for years. With these persistent chemicals of concern, there is the possibility for accumulation in soil and bioaccumulation in animals and humans ingesting grass and crops grown on the soil.

Based on the M2L and WEP studies, the most widespread organic contaminants in wastes includes:

- PAHs;

- PCBs;

- PFOS;

- dioxins and furans;

- phthalates;

- triclosan; and

- glyphosate/AMPA.

6.3.1.4   Plastics

The potential presence of microplastics in wastewater is becoming a concern, as these can then become incorporated into biosolids and sewage sludge which is then spread to land.

Microplastics can potentially impact soil ecosystems, crops and livestock either directly or through the toxic and endocrine-disrupting substances added during plastics manufacturing. These substances include short/medium-chain chlorinated paraffins (candidates for inclusion in the Stockholm Convention) and plasticisers, which can represent up to 70% of the weight of plastics. Endocrinologically active alkylphenols, such as bisphenols, and flame retardants including several banned brominated compounds comprise up to 3% by weight of some plastics. During use, plastic polymers efficiently accumulate other harmful pollutants from the surrounding environment, including a number of persistent, bioaccumulative and toxic substances, e.g. PCBs, dioxins, DDTs and PAHs (Nizetto, 2016). As yet, there is no standardised method for assessing the levels of microplastics in wastewaters, sludges and soils and consequently the presence of microplastics in wastes and agricultural soils was not assessed in M2L, WEP or CIP programmes and the full potential extent of the issue has not been properly assessed.

With respect to the M2L data, the possible presence of plastics can be inferred from the detection of certain organic contaminants present in plastics (e.g. phthalates, used as plasticisers), but the presence of micro-plastics and whether or not these are acting as "sponges" for adsorption of other organic contaminants is not clear.

6.3.1.5   Asbestos

The WEP data for inert waste landfills and deposit for recovery demonstrates that asbestos-containing materials are widely present in "inert" materials, although rarely in sufficient quantities to categorise the materials as hazardous. Gypsum/plasterboard was also widely identified as a physical contaminant, which in turn gives rise to high sulphate concentrations (sulphate being one of the inorganic compounds referred to above). These WEP data also highlighted issues relating to the presence of vegetation and other non-inert material in "inert" waste.

6.3.2   What Control do Operators / Farmers Have Over the Types of Waste They are Accepting?

The degree of control varies by operator and material, and a discussion of the degree of control according to the spreading type and landspreading activity is presented below. In the case of sewage sludge, operators applying this material to land will have little control over the wastewater or sludge streams that enter the WwTW; this is under the control of the water company. However, while the operators have little control over the composition of the sewage, they can determine how it is treated and spread. There is evidence of the involvement of multiple different operators, waste brokers and contractors between the sewage sludge leaving the WwTW and being spread on fields. The increase in the number of parties involved results in:

- less transparency and greater difficulty in tracking the waste from source to field; and

- greater risks to the receiving fields in the event that an issue is identified with a particular batch of sludge.

The results of the WEP study indicate a lack of clarity in classifying waste streams (e.g. some hazardous wastes being miscoded, and the widespread use of "catch-all" codes such as 16 10 02 for liquid effluents). Additionally, the absence of requirements for environmental permits at WwTW, coupled with the anecdotal evidence from waste producers that wastes are increasingly being redirected to WwTW, means the degree of control that water companies have over the wastes entering WwTW is decreasing. This results in less control over which constituent compounds may ultimately end up in sludge.

In the case of inert waste and material deposited for recovery, the WEP data suggest that the current systems are not adequate to control the quality of materials accepted. The WEP programme indicated widespread problems with waste acceptance, both in terms of physical quality or material source, and chemical quality. It would appear that operators in these circumstances are choosing not to exercise stringent control, and clearly both waste producers and site operators have incentives to accept as much materials as possible.

In the case of pig and poultry ash, the wastes are generated on the site at which they are applied, and hence the operator has complete control over the waste types. For other materials applied to land, again the amount of control varies according to the operators and waste stream.

In general, for wastes spread under SR2010 No.4, most farmers have little control over the wastes that are spread on their fields and are reliant on the operator confirming that the individual waste streams do not deviate from the wastes characterised in the deployment and accompanying agricultural benefit statement. Equally, in many cases the actual spreading is subcontracted to a contractor, and it is assumed that the contractor has been provided sufficient information from the operator to conduct the landspreading safely (e.g. the contractor has been made aware of buffer zones, changes in spreading rates, etc.).

Conversely, there were examples where the waste producer, waste operator, contractor and farmer were all part of the same extended family or parent company. In these scenarios, without the involvement of any independent parties, there are no additional checks and balances and the landspreading activities may be open to abuse, either through management of the landbank solely to maximise the volume of waste which can be spread, or through deliberate masking of potential illegal spreading.

Where the spreading involves mixed waste streams, there is little transparency in how the mixed wastes were formed, and whether the mixed wastes comprise the mixture detailed in the agricultural benefit statement, which ultimately confirms that the spreading of the wastes confers a benefit to the receiving soils and benefitting crops.

However, the responsibility for providing accurate information is a two way process, with the operators dependent on the farmers correctly identifying which benefitting crops are to be grown in which fields. A number of examples were identified in M2L1, where the farmer had wrongly identified the field to be spread, or altered the benefitting crop after spreading, with resulting over application of waste.

6.3.3   Does the EA Have Clarity Over What Types of Waste is Being Recovered by Application to Land?

The results of the M2L Phase 1 and WEP studies demonstrated the difficulty for the EA in keeping track of the types of waste that are either entering biowaste treatment, WwTW, or being applied directly to land.

Issues included:

· Miscoding of wastes. As noted above, the widespread miscoding and use of "catch-all" codes makes it difficult to understand the types of waste that are present in materials which end up being spread to land; and

· Mixed applications.

Of the two issues identified above, the latter is arguably the most difficult for the EA to assess. The use of multiple waste streams is increasing, presumably as it offers the waste operators maximum

flexibility with respect to managing the wastes produced by their clients. It is this flexibility, and the ability to adapt to last minute changes to the mix of wastes being spread, which may lead to longer term issues. In some cases, the mixed wastes are being described as a mixed waste in the deployment, without any further details on the individual constituent wastes. There is potential for individual waste streams containing hazardous waste to be included within the mixed waste, with the danger that any transparency in tracking this waste is subsequently lost.

6.3.4   Are Producers Exercising Their Duty of Care With Respect to Waste Which is Ultimately Recovered by Application to Land?

None of the WEP, CIP or M2L programmes included explicit evaluation of the Duty of Care (DoC) procedures being followed by waste producers. Nevertheless, both M2L1 and WEP encountered numerous instances of waste being either mis-described or inaccurately coded. Ensuring that waste is accurately described is a critical part of the duty of care requirements. The extent to which waste producers assure themselves that their waste is suitable for biotreatment or direct application to land is not known and would require a separate study.

6.3.5   Are Biotreatment Sites Consistently Applying the Jacobs Framework, and is it Appropriate for all Wastes?

The WEP programme highlighted numerous examples of wastes being accepted at biowaste treatment facilities that did not comply with the Jacobs Framework.

6.4   Contaminants of Concern Entering Biotreatment or Applied to Land

6.4.1   How do Operators Currently Assess the Biodegradability of Substances in Wastes Entering Biotreatment or Spread to Land?

The Jacobs Framework was developed to guide regulators, operators and other stakeholders when considering applications for bespoke wastes for biological processing. The purpose of the framework is to identify a route through the process for assessing the suitability of bespoke wastes for biological treatment and the evidence that will be required to support bespoke permit applications for the biological treatment of such wastes.

6.4.2   Are There Thresholds for Evaluating the Biodegradability of These Substances and the Effectiveness of Biowaste Treatment?

The Framework presents general inhibition values for aerobic and anaerobic treatment for a range of parameters known to be inhibitory to aerobic and anaerobic processes. If the waste is outside of these values it does not exclude it from being suitable for biological treatment. However, the operator may need to apply additional measures and demonstrate their efficacy to allow the waste to be treated within the proposed system.

Reliance on the Jacobs Framework to manage contaminants entering the biowaste treatment system has the following drawbacks:

·   the inhibition values relate to the biowaste treatment processes themselves, not to the final use of the treated biowaste;

·   only a limited number of organic compounds have inhibition values, and for many of these the inhibition values apply to anaerobic treatment only; and

·   the onus is placed on the operator to correctly identify those substances present in the waste, analyse for them, and then confirm their biodegradability. Therefore substances which may be present as contaminants in trace amounts, rather than as main components of the waste stream, may not be identified and their treatability not assessed. Widespread mis-description of waste makes it even harder to estimate what contaminants may be present in a given waste stream.

Even if wastes meet the Jacobs framework, illustrating that aerobic and anaerobic treatment is theoretically possible, how consistently successful the actual treatment of the wastes is in large commercial operations receiving wastes with slightly differing composition in each batch is unclear.

6.4.3   Are There Thresholds for all Contaminants Likely to be Found in Wastes Applied to Land?

The existing thresholds given in SUiAR relate mainly to selected PTEs, with some reference to physical contaminants and inorganic compounds. Proposed European thresholds extend this list to include PAHs, but for a wide range of organic contaminants there are no thresholds for application to land (see Appendix D).

Based on a review of the deployments in M2L1, very few of waste analysis provided included analytical testing of other contaminants other than the PTEs specified in SUiAR, unless additional testing was specifically requested by the EA. This suggests that the producers / operators are over reliant on characterising wastes solely with respect to PTEs and not considering testing for other contaminants which may be present.

Ultimately, one of the key drivers of the M2L, WEP and CIP projects is to identify which contaminants may be present within the waste, and once this is better understood, particularly with respect to emerging toxics, then additional research projects can be focussed on understanding the behaviour of these contaminants in agricultural soils with respect to factors such as residence time, solubility, bioaccumulation and inhibition of natural soil bacteria. This information is needed before risk assessment criteria can be developed.

Risk assessment tools are commonly used by the contaminated land industry to assess the risks posed by various soil contaminants. However, these tools generally require site-specific information and technical expertise to use, and hence are not readily applicable to materials applied to land. In recognition of this gap, the EA developed WALTER (Waste Applied to Land: Tool for Environmental Risk) to assess dietary exposures from waste applied to agricultural land, by estimating the transfer of contaminants from soil through crops and livestock into the human diet.

AECOM understands that the Food Standards Agency (FSA) is currently funding work with the overall aim of investigating the potential transfer of organic contaminants into food arising from the use of "recycled waste" in agriculture. Initial findings from this research were published by Rigby et. al (2015). and the results were reviewed and discussed in Section 5, above. This research is intended to improve the predictions made by generic models (e.g. WALTER) of food chain transfers.

Based on the results of M2L1, M2L2 and WEP, the following organic contaminants should be prioritised in terms of setting thresholds:

·   persistent organic pollutants and proposed additions to the Stockholm Convention (e.g. PDBEs, PFOS, and PFOA);

·   phthalates (especially DEHP);

·   antibiotics and anti-bacterial chemicals (e.g. erythromycin, Triclosan, and Triclocarban);

·   personal care products (e.g. galaxolide) and microplastics; and

·   human and veterinary medicines (e.g. ibuprofen, propranolol);

A summary of relevant UK thresholds (including reference to existing and proposed European thresholds) is presented as Appendix D.

6.4.4   Are These Thresholds Appropriate?

The recent European Joint Research Centre (JRC) project included an overview of thresholds across multiple European jurisdictions, and recommended a series of updated thresholds. As noted in the FATE-SEES report "*After 20 years since its adoption, the Directive appears to be entirely outdated. Indeed, Member States have – on the basis of new scientific insight in the effects of sludge on land – enacted and implemented much stricter limit values for heavy metals as well as for contaminants, which are not addressed in the Directive.*"

For PTEs, the recommended European thresholds are broadly similar to the existing PAS100/110 and SUiAR thresholds, which implies that the current thresholds are appropriate.

For organic contaminants, some countries have proposed thresholds, but these can vary significantly from one country to another. For example, many European countries have proposed limits for PCBs in biosolids and composts, ranging from 0.08 mg/kg in Denmark to 0.8mg/kg in France (Appendix D.4).

Until further studies are completed and a more coherent understanding of the relative prevalence and risks of these compounds in the environment is obtained, it is difficult to determine which of the various limits is most appropriate. As noted in the FATE-SEES report "*there is growing scepticism whether land application of sewage sludge is a sustainable method of dealing with that waste stream. The underlying concerns for these actions result in particular from the fact that the majority of contaminants in general and organic contaminants in particular potentially contained in sewage sludge are not known and not sufficiently tested before applying sludge on land. An extensive and meaningful risk assessment would require however full knowledge of the number, the concentration and the effects of all organic contaminants found in sewage sludge. Filling the gaps in knowledge regarding the concentration, fate and toxicity of sludge-borne contaminants is critical if risks associated with land application are to be adequately characterized*".

6.4.5   Is there Evidence of Potentially Harmful Concentrations of Substances Being Applied to Land?

Based on the M2L study, and comparing analytical data against the limits in the PAS100/110 and SUiAR regulations, there is little direct evidence that PTEs are being applied to land at harmful concentrations for an individual application.

In addition to screening soil concentrations against PTE limits, the Smart Form allows an initial assessment of risks to human health and ecological receptors. No risks to ecological receptors from PTE were identified during either M2L1 or M2L2 for an individual application.

The Smart Form does indicate potential enrichment of PTE levels in soils from a single application. However, the cumulative effect of enrichment from multiple applications of waste over a number of years has yet to be assessed, Currently, the guidance in the SUiAR regulations requires analysis of PTE concentrations in receiving soils once every twentieth year. The levels of enrichment identified for individual spreading events are sufficiently high that year on year applications could result in significant increases in PTE concentrations in the 20 year period between testing, to the extent that the soil may no longer be suitable for supporting crop growth.

In addition, the PTE suite does not include all of the potential contaminants present in waste which may pose a risk to human health, controlled waters, and the wider environment.

Ecological risks were assessed by screening soil concentrations against Soil Screening Values (SSV) derived for assessing potential risks to ecological systems from 11 contaminants including benzo(a)pyrene, pentachlorophenol, toluene and selected metals (EA, 2008). The SSVs are conservative and are to be used for screening to provide an early indication of the potential for risks to exist. Concentrations of contaminants exceeding the SSVs may indicate a concern, which may warrant further investigation or risk evaluation.

However, the following contaminants were identified at levels that may present a risk to human health:

·   benzo(a)pyrene;

·   dioxins and furans; and

·   manganese.

In the absence of receiving soil data, default values corresponding to the median from the national dataset from the SHS were selected. While these may not be representative of the soils present at the site, they are considered to be representative of average soil conditions across the UK.

The M2L studies have also identified the presence of physical contaminants in soil including plastics and sewage screenings which may impact the long term quality of the landbank. In addition, a number of organic contaminants were identified which were ubiquitous in wastes and soils and could not be assessed using the current version of the Smart Form, including pesticides (glyphosate and daughter product AMPA), plasticisers including phthalates, PFOS, galaxolide, and triclosan.

The CIP studies have identified a number of contaminants in sludges which may be spread to land, including human medicines, antibiotics, and antibacterial chemicals. However, it is noted that CIP1 and CIP2 targeted effluents and sludges at the place of production, which may not necessarily represent the final material being spread to land.

The WEP Deposit for Recovery sampling indicated widespread presence of asbestos and sulphate (from gypsum) in construction-derived materials. Risk assessments were not carried out and it is not therefore possible to assess whether the concentrations recorded are harmful.

6.5   Persistence and Build-up of Contaminants of Concern in Soil

6.5.1   Are the Thresholds and Guidance Adequate to Evaluate the Risks From Build-up of Persistent Substances?

There are a range of thresholds which potentially apply to materials spread to land, originating from the number of guidance documents. At present, the UK guidance and regulations are almost entirely focused on PTEs.

The Jacobs Framework includes a wider range of potential contaminants which may inhibit the biotreatment process, but this testing is not a mandatory requirement and is focussed primarily on the effects on biowaste treatment processes, rather than the final impacts on the quality of the outputs from biowaste treatment or the receiving soils, crops and environment.

The EU's JRC has been considering the publication of new thresholds for determining end-of-waste status for the outputs of biowaste treatment, and these are summarised in Appendix D.5.

It is becoming clear from the results of CIP2 and other studies that there are other contaminants present in waste whose effects in soil environments have not been well studied and there remains significant uncertainty regarding the potential longer term impacts of these contaminants on the quality of the land bank, and the potential for bioaccumulation of more persistent organic contaminants within receiving soils, and potentially crops grown on the receiving soils.

6.5.2   Is there Evidence of Potential Harm Caused Build-up of Substances in Soil?

Neither CIP nor WEP sought direct evidence of harm to the environment due to the build-up of contaminants in soil, and targeted the composition of the wastes.

M2L1 involved sampling of receiving soils, but the one-off nature of the sampling was not sufficient to demonstrate any change in soil contaminant concentrations over time, or any harm that this would cause.

Some comments were received from farmers during the M2L1 field work which indicated that there were some concerns over the negative impacts of certain wastes on crop yields. No soil samples were collected or analysed as part of M2L2.

Given the ubiquity of certain relatively persistent organic contaminants in material applied to land (e.g. PAHs and PCBs), there may be value in carrying out studies to assess:

   a.   whether concentrations of these compounds in soil are increasing over time as materials are spread to land;

   b.   whether there is evidence either of actual harm occurring, or contaminant concentrations at which there is a significant risk of harm to the food chain, human health or the wider environment; and

c.   the potential for bioaccumulation of some of these contaminants in soils, receiving crops, livestock and ultimately the human food chain. Particular concerns revolve around the role of anti-microbial chemicals and the effect which these could have on naturally occurring soil bacteria and fauna intrinsic in maintaining healthy soil conditions.

6.6   Risks to Controlled Waters

6.6.1   Is there Evidence of Potential Harm Caused by Leaching of Substances to Groundwater and Surface Water?

Based on the findings of the M2L projects, there is evidence of impacts to surface waters, typically in the form of pollution incidents resulting from accidental release of wastes from storage facilities or during spreading. Several of the case studies also referenced eutrophication of adjacent water bodies resulting from poorly managed spreading operations.

Impacts to groundwater are more difficult to link directly to spreading of wastes. Circumstantial evidence from the modelling of RAN in nitrate safeguard zones completed as part of M2L1 indicated spreading of wastes outside of the closed periods could still result in a theoretical risk to groundwater from leaching of nitrate. Increasing concentrations of nitrate in some aquifers in the UK is believed in part to be the result of leaching of nitrates from fertilisers and wastes applied to land.

While the presence and behaviour of nutrients (particularly nitrate) and more established contaminants such as heavy metals in controlled waters are well understood, there is little information regarding the current levels, risks and impacts from emerging toxics and other organic pollutants which could be present in wastes being spread to land and ultimately end up in surface water, groundwater and the marine environment.

6.7   Compliance / Non-Compliance

From the results of M2L Phase 1, there is uncertainty over whether the current permitting regime is sufficiently robust to allow proper control of the increasing complex mixtures or waste being spread to land in England. Based on the results of a poll of EA staff, landspreading of wastes under standard rules permits at least requires notification of the EA and afford the opportunity for staff to audit the landspreading activities, This has recently been strengthened by the addition of the pre-notification requirement in advance of the planned commencement of spreading.

There are greater concerns regarding spreading activities carried out under exemptions, the SUiAR rules, and spreading of quality protocol wastes. These concerns have been borne out by the findings of the biowaste treatment project.

6.7.1   Quality Management and EA Permitting

There are some key challenges the EA permitting staff and area officers face in reviewing and assessing the suitability of landspreading activities including:

·   time constraints associated with reviewing permits, which are tending to become increasingly complex and are often incorrect and incomplete and require several iterations prior to approval;

·   intelligence gathered by the local area officers regarding the performance of an operator or farmer in their area isn't always passed back to the permitting staff for consideration when assessing whether to authorise a permit;

·   the increasing number of different parties involved between production of a waste and spreading of the waste to land, make it difficult to accurately trace individual shipments of waste from cradle to grave;

·   increasing use of mixed wastes increases the risks that hazardous wastes may end up within these waste streams; and

· disappearance of problematic waste streams previously disposed of to land under standard rules permits. There is intelligence that some of these wastes are ending up in composting and/or AD facilities, with spreading activities not subject to the same level of scrutiny.

6.7.2   Definition and Assessment of Benefit

Findings from Phase 1 of M2L identified a number of situations where the addition of nutrients exceeded the requirement of the receiving crop and may be considered over application. The most common example was spreading of mixed wastes, where one or more of the wastes was substituted or missing, with the result that the final mixture did not match the waste described in the agricultural benefit statement and used to determine the spreading rates.

However, based on the findings of the Smart Form and soil sampling, the over application of nutrients does not generally appear to result in a long term impact on the soil, with short term impacts to controlled waters through leaching likely to be more of a concern.

Other longer term risks to the landbank from bioaccumulation of organic pollutants has been discussed above, but perhaps the biggest risk to the landbank is from the spreading and incorporation of physical contaminants into agricultural soils (for example plastics, microplastics.

In addition to impacts to the landbank, additional risks to farmers may be associated with the presence of asbestos in wastes.

6.7.3   Compositional Changes, Emerging Toxics and Other Contaminants

As mentioned previously, due to the reduction in more traditional heavy industry, there is a greater proportion of effluents derived from household waste at WwTW. Coupled with advances in pharmaceutical and healthcare industries, there is an ongoing shift away from the more well understood traditional contaminants (i.e. heavy metals) to an ever increasing list of new chemicals, whose behaviour in the environment is not well understood.

In addition to the emerging toxics (including phthalates, antimicrobials, personal care products) there is also evidence of many persistent organic pollutants (e.g. DDT, lindane) whose use in Europe and the UK has been prohibited for many years. Despite the apparent ban on using these compounds, these compounds are still being detected in UK waste streams, some having a ubiquitous presence, illustrating the highly persistent nature that these compounds can have in the environment.

7. Conclusions and Recommendations

7.1 Summary

The aims and objectives of Phase 2 of the Materials to Land project were to:

· provide an assessment of materials being spread to land, using information gained through the wider Waste Enforcement Programme (WEP) in order to better ascertain the risk to human health and the wider environment from their use;

· provide information to support a wider review of the regulations around the treatment and use of sewage sludge as a material spread to land;

· provide information to support a planned consultation on revisions to the exemptions under the Environmental Permitting Regulations (EPR);

· create recommendations for improvements in how waste derived materials spread to land are regulated, described, used, and compared to organic and manufactured or quarried fertiliser and soil conditioners; and

· utilise the information obtained to inform the EA, government, and industry about the benefits and risks associated with using waste derived materials on land.

This report has reviewed the potential risks associated with current landspreading activities being conducted in England, based on the findings of the WEP (including the M2L projects) and taking into consideration the findings from other pertinent studies, including the CIP1 and CIP2 projects.

The WEP and M2L projects have included the sampling of numerous waste streams plus, where possible, the fields where waste has been spread. The samples were taken at, or close to, the place of waste application. The collated data provides insights into the range of potential contaminants in waste that could pose a risk to human health and the wider environment. These substances include both those routinely tested for in waste analysis, such as potentially toxic elements (PTEs), but also many organic pollutants including PAHs, PCBs and compounds of emerging concern such as PFOS and antimicrobial chemicals. Risks from these chemicals have been reviewed against existing and proposed standards and using methodologies being implemented by regulators.

The information presented in this report could be used, where appropriate, to support further studies and review of, or consultations on, changes to the existing regulations and processes used to manage landspreading.

The key findings are summarised below along with recommendations for further actions.

7.2 Key Findings

7.2.1 Changes in Landspreading

The nature and type of landspreading activities currently being undertaken in England and Wales have changed considerably since the introduction of the current permitting regime in 2010. The nature of the wastes being spread is becoming increasingly complex, marking a move away from relatively well characterised single waste streams from recognised suppliers, to more complex mixed waste streams from a larger and more diverse range of operators.

The number of parties involved in waste spreading has also changed, moving away from a simple transparent chain comprising the producer, waste operator and farmer, to longer and more convoluted chains which can include a number of different middleman including waste brokers, contractors and subcontractors. With the increased complexity, it is becoming more difficult to track wastes from the place of production to the receiving fields. There is also an increased opportunity for mistakes to arise, with an associated increase in risk associated with landspreading, including spreading of materials which are not compatible with regulations, do not confer benefit, and potentially also being spread to land as this represents a more convenient and cost effective method of waste disposal.

The role of the EA in effectively regulating landspreading activities is becoming more difficult, with increased time pressures and reduced budgets leaving less time for staff to review each permit application. At the same time, there is evidence of an increasing number of waste streams being diverted to facilities that operate in accordance with Quality Protocols, such as composting and anaerobic digestion, where the resulting material can be spread to land with less regulatory oversight, again increasing the potential risks to the landbank from landspreading of these materials.

7.2.2   Changes in Waste Composition

Due to reductions in heavy industry, coupled with changes in intensive farming practices, advances in pharmaceutical and healthcare fields and the wide array of chemicals now present in everyday household products, the nature and composition of waste streams are changing. When the spreading of sewage sludge was first investigated in the 1980's, the contaminants of concern associated with sewage sludge were restricted to a simple list of selected metals and fluoride (referred to as "potentially toxic elements, PTEs).

Technological advances in analytical methods have allowed the detection of contaminants at lower and lower levels. This has led to the identification of a wider range of contaminants in wastes, soils, crops, livestock and the human food chain that were previously unidentified. As our understanding of the behaviour and longevity of some contaminants in the natural environment has improved (and continues to do so), the number of potential contaminants present in wastes and soils, which may pose a risk to human health and the wider environment, has expanded. Our knowledge is continually evolving and currently includes the following as a non-exhaustive list: PAHs, PCBs, dioxins and furans, Per- and Polyfluoroalkylated Substances (PFAS e.g. PFOS and PFOA), PDBEs, phthalates, antibiotics, human and veterinary medicines, pesticides, and antimicrobial chemicals.

In addition to chemical constituents of waste, there are also concerns over physical contaminants particularly with regard to plastics and microplastics. The latter are of particular concern due to their small size, ability to be retained by WwTW (Carr et al., 2016), and ability to potentially sequester other contaminants (e.g. PCBs, dioxins, DDTs and PAHs) which are subsequently released as the plastics break down in soils (Nizetto at al., 2016).

The fate and behaviour of many of these compounds in the soil environment are only beginning to be investigated, and the risks associated with these contaminants is not yet understood. Current testing suites for characterising wastes and soils remain largely unchanged since the introduction of SUiAR, despite increasing evidence of the identification of low levels of contaminants in waste streams. There are uncertainties over the levels of these contaminants present in wastes spread to land. Specifically, there is uncertainty over whether these contaminants pose a risk to human health and the wider environment, either at the levels present in wastes or through enrichment in soils due to repeated applications over successive years.

7.3   Recommendations

AECOM has identified a number of areas for further assessment and possible changes to the methods used to manage and control landspreading. These would address some of the issues identified above and in doing so provide farmers, operators and the public with greater confidence in the benefits of applying wastes to land.

The recommendations for further assessment are:

· further investigation of the occurrence, levels, longevity and behaviour of the full range of toxic elements and organic pollutants in waste. In particular, further research should be carried out into the presence of organic pollutants, including compounds of emerging concern, in individual waste streams.

· Investigation of the existing background levels of these toxic elements and organic pollutants in agricultural soils, plus the potential for bioaccumulation and ultimately whether the potential build-up of these chemicals poses a longer term threat to the productivity of the landbank;

The following changes to the management and control of landspreading could be considered:

· reduction in the number and type of waste streams which can be spread to land under a single deployment;

· a simplification in the number of EWC codes which can be spread to land and limitations on codes that encompass a wide range of waste;

· improved cradle to grave waste auditing allowing better tracking of individual waste streams from the place of production to the receiving field;

· tightening of the conditions under which wastes can be stored and spread to land to reduce the risks from poorly managed storage and spreading activities;

· introduction of advantageous operating conditions and reduced regulatory oversight for well performing operators, coupled with increased oversight, financial penalties and trading bans to target continually poor performing operators / farmers; and

· introduction of independent validation (e.g. by FACTS trained advisors) that spreading activities have been conducted safely and in accordance with the conditions of the permit. This measure could be accompanied by an additional tier of validation testing of the soil to be undertaken by the operator following spreading to confirm that no contaminants were introduced.

8.   Abbreviations Used in this Report

Abbreviation	Meaning
AECOM	AECOM Infrastructure & Environment UK Limited
ABPR	Animal By-Product Regulations
AD	Anaerobic Digestate
ADAS	Agricultural Development and Advisory Service
AMPA	Aminomethylphosphoric acid
APHA	Animal and Plant Health Agency
ASP	Activated Sludge Process
BDE	Bromodiphenyl Ether
BF	Biological-filter
BNR	Biological Nutrient Removal
BOD	Biological Oxygen Demand
BRC	British Retail Consortium
Bsi	British Standards Institute
$Ca(OH)^2$	Calcium Hydroxide
CaO	Calcium Oxide
CFU	Colony Forming Unit
CIP	Chemical Investigation Programs
CLO	Compost Like Output
COD	Chemical Oxygen Demand
COGAP	Code of Good Agricultural Practice
CoV	Coefficient of Variation
DDD	Dichlorodiphenyldichloroethane
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
Defra	Department for Environment, Food & Rural Affairs
DEHP	Diethylhexylphthalate
DfR	Deposit For Recovery
DoC	Duty of Care
DST	Decision Support Tool (previous name for the Smart Form)
DW	Dry Weight
EA	Environment Agency
Eco QRA	Ecological Quantitative Risk Assessment
EMEA	European Medicines Agency
EPR	Environmental Permitting Regulations
EU	European Union

EWC	European Waste Code
FACTS	Fertiliser Advisors Certification and Training Scheme
FiT	Feed in Tariffs
FSA	Food Standards Agency
HBCDD	Hexabromocyclododecane
HCH	Hexachlorocyclohexane
HHQRA	Human Health Quantitative Risk Assessment
HSE	Health and Safety Executive
ICES	International Council for the Exploration of the Seas
JRC	Joint Research Council
LOD	Limit of Detection
LoW	List of Wastes
M2L	Materials to Land
Max.	Maximum
MBR	Membrane Bio-reactor
MDL	Method Detection Limit
Min.	Minimum
MPN	Most Probable Number
NCP	Nominated Competent Persons
ND	Not detected above analytical laboratory method reporting limit
NPS	National Permitting Service
NVZ	Nitrate Vulnerable Zone
OCDD	Octachlorodibenzo-p-dioxin
PAH	Polycyclic Aromatic Hydrocarbons
PAS	Publicly Available Specification
PBDE	Polybrominated Diphenyl Ethers
PCB	Polychlorinated biphenyls
PCDD/dioxins	Polychlorinated dibenzo-p-dioxins
PCDF/furans	Polychlorinated dibenzofurans
PFAS	Per- and Polyfluoroalkyl Substances
PFBA	Perfluoro-n-butanoic acid
PFBS	Perfluoro-1-butanesulfonate
PFDA	Perfluoro-n-decanoic acid
PFDoA	Perfluoro-n-dodecanoic acid
PFHpA	Perfluoro-n-heptanoic acid
PFHpS	Perfluoro-1-heptanesulfonate
PFHxA	Perfluoro-n-hexanoic acid

PFHxS	Perfluoro-1-hexanesulfonate
PFNA	Perfluoro-n-nonanoic acid
PFOA	Perfluoro-n-octanoic acid
PFOS	Perfluorooctane Sulfonate/ Perfluoro-1-octanesulfonate
PFOSA	Perfluoro-octanesulfonamide
PFPA	Perfluoro-n-pentanoic acid
PFUnA	Perfluoro-n-undecanoic acid
PHE	Public Health England
PLA	Poultry Litter Ash
PNEC	Predicted No Effect Concentrations
POP	Persistent Organic Pollutants
PSD	Particle Size Distribution
PTE	Potentially Toxic Elements
QP	Quality Protocol
REA	Rapid Evidence Assessment
ROC	Renewable Obligation Certificates
SGZ	Safeguard Zone
SHS	Soil Herbage Study
SNIFFER	Scotland and Northern Ireland Forum for Environmental Research
SR	Standard Rules
SSSAFO	Storing Silage, Slurry and Agricultural Fuel Oil
SSV	Soil Screening Value
SUiAR	Sludge (Use in Agriculture) Regulations
SVOC	Semi-Volatile Organic Content
TBT	Tributyltin
TCDF	Tetrachlorodibenzofuran
TDE	See DDD
TDS	Total Dissolved Solids
TEQs	Toxic Equivalents
TGN	Technical Guidance Note
TIC	Tentatively Identified Compounds
UK	United Kingdom
UKAS	United Kingdom Accreditation Service
UKSO	UK Soil Observatory
UKWIR	UK Water Industry Research
USEPA	United States Environmental Protection Agency
VOC	Volatile Organic Content
WAC	Waste Acceptance Criteria

WALTER	Waste Applied to Land: Tool for Environmental Risk
WEP	Waste Enforcement Program
WFD	Water Framework Directive
WHO	World Health Organisation
WM	Waste Management
WRAP	Waste & Resources Action Programme
WwTW	Wastewater Treatment Works
w/w	By weight

9.   References

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Appendices:

Appendix A Factual Reports

See attached pdf documents.

Appendix B Interpretative Reports

See attached pdf documents.

Appendix C Summary of Analytical Results

Contents

Table C1 : Phase 1 Data - All Stackable Waste - Metals Analysis

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Suite A - Metals - (Liquid)	Extractable Calcium (Top Soil)	mg/l	28	28	266	94100	5461.39
	Extractable Magnesium (Top Soil)	mg/l	32	27	42.9	3120	291.55
	Extractable Potassium (Top Soil)	mg/l	32	27	29.4	29700	1775.01
	Extractable Sodium (Top Soil)	mg/l	32	26	71.6	15700	1518.80
Suite A - Metals - (Solids)	Aluminium	mg/kg	34	34	500	90900	11476.74
	Antimony	mg/kg	34	20	0.645	10.7	3.16
	Arsenic	mg/kg	34	28	0.632	64.3	8.48
	Barium	mg/kg	34	34	12.6	486	102.35
	Beryllium	mg/kg	34	34	0.0107	5.05	0.41
	Bismuth	mg/kg	34	19	1.03	7.45	2.63
	Boron	mg/kg	34	34	0.744	130	13.18
	Boron (Water Soluble)	mg/kg	26	16	1.07	69.4	7.86
	Cadmium	mg/kg	34	33	0.0355	11.6	1.09
	Calcium	mg/kg	34	34	2150	293000	107742.06
	Chromium	mg/kg	34	34	1.68	92.8	16.12
	Chromium, Hexavalent	mg/kg	31	3	2.63	4.91	3.57
	Cobalt	mg/kg	34	34	0.653	11.2	3.83
	Copper	mg/kg	34	33	4.87	398	77.34
	Fluoride, 2:1 water soluble	mg/kg	12	8	1.01	7.89	2.88
	Iron	mg/kg	34	32	1150	35500	10317.50
	Lead	mg/kg	34	34	1.17	911	66.95
	Lithium	mg/kg	34	33	1.06	63.6	11.45
	Magnesium	mg/kg	34	33	280	42600	3819.91
	Manganese	mg/kg	34	34	42.8	6220	478.54
	Mercury	mg/kg	34	9	0.162	0.721	0.33
	Molybdenum	mg/kg	34	33	0.223	14.5	2.13
	Nickel	mg/kg	34	34	0.987	55.2	11.96
	Phosphorus	mg/kg	33	33	36.4	55800	5148.59
	Potassium	mg/kg	34	34	114	196000	8747.47
	Selenium	mg/kg	34	16	1.04	25.6	3.98
	Silver	mg/kg	34	1	16.2	16.2	16.20
	Sodium	mg/kg	34	34	18.5	11100	1985.75
	Strontium	mg/kg	34	34	5.79	533	205.23
	Tellurium	mg/kg	17	7	1.36	2.56	2.14
	Thallium	mg/kg	34	1	7.8	7.8	7.80
	Tin	mg/kg	34	22	0.295	33.7	7.39
	Titanium	mg/kg	34	34	6.6	372	62.51
	Vanadium	mg/kg	33	33	1.38	90.2	14.04
	Zinc	mg/kg	34	34	30	1820	215.48

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration

Table C2: Phase 1 Data - All Non-Stackable Waste - Metals Analysis

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Suite A - Metals - (Liquid)	Extractable Calcium (Top Soil)	mg/L	4	4	1180	2050	1500.00
	Extractable Magnesium (Top Soil)	mg/L	4	4	126	879	522.75
	Extractable Potassium (Top Soil)	mg/L	4	4	42.7	5340	2655.68
	Extractable Sodium (Top Soil)	mg/L	4	4	145	5200	2808.75
Suite A - Metals - (Solids)	Aluminium	mg/kg	5	5	954	3350	2172.80
		µg/l	27	25	8.18	35600	3193.46
	Antimony	mg/kg	5	5	0.824	5.38	2.08
		µg/l	27	25	0.228	38.2	4.06
	Arsenic	mg/kg	5	5	1.11	9.69	3.33
		µg/l	27	27	0.12	259	22.08
	Barium	mg/kg	5	5	11.1	61.4	33.14
		µg/l	27	26	0.304	1290	178.99
	Beryllium	mg/kg	5	4	0.0523	0.156	0.12
		µg/l	27	6	0.07	3.77	1.23
	Bismuth	mg/kg	5	3	1.92	2.69	2.38
		µg/l	27	3	0.245	10.4	3.92
	Boron	mg/kg	5	5	2.21	31.7	11.89
		µg/l	49	37	66.3	96700	5426.13
	Boron (Water Soluble)	mg/kg	3	1	9.03	9.03	9.03
	Cadmium	mg/kg	5	5	0.0502	0.743	0.30
		µg/l	27	12	0.109	1.76	0.53
	Calcium	mg/kg	5	5	4840	229000	85108.00
		mg/L	28	28	19.2	3400	400.06
	Chromium	mg/kg	5	5	3.88	170	40.30
		µg/l	27	27	0.309	183	32.67
	Chromium, Hexavalent	mg/kg	5	0			
		mg/L	27	3	0.221	10.5	3.73
	Cobalt	mg/kg	5	5	0.782	17	4.81
		µg/l	27	26	0.066	196	28.07
	Copper	mg/kg	5	5	11.1	62	34.48
		µg/l	27	26	1.33	991	64.86
	Fluoride	mg/L	30	16	0.998	685	87.36
	Iron	mg/kg	5	5	1580	22700	8492.00
		mg/L	28	28	0.0513	359	49.48
	Lead	mg/kg	5	5	3.01	16.8	7.82
		µg/l	27	26	0.058	397	21.52
	Lithium	mg/kg	5	4	1.15	20.4	7.90
		µg/l	27	25	2.12	604	48.50
	Magnesium	mg/kg	5	5	267	4660	2517.40
		mg/L	28	28	0.891	171	43.53
	Manganese	mg/kg	5	5	76.7	377	156.68
		µg/l	27	27	1.3	20300	1880.41
	Mercury	mg/kg	5	1	0.357	0.357	0.36
		µg/l	29	4	0.0321	4.2	1.18
	Molybdenum	mg/kg	5	5	0.612	12.1	3.59
		µg/l	27	26	0.275	585	47.68
	Nickel	mg/kg	5	5	3.25	110	27.42
		µg/l	27	26	1.64	383	104.52
	Phosphorus	mg/kg	5	5	207	32400	17563.40
		µg/l	27	27	381	265000	56731.89
	Potassium	mg/kg	5	5	398	9160	5985.60
		mg/L	28	28	19.1	2240	525.44
	Selenium	mg/kg	5	2	1.55	2.9	2.23
		µg/l	27	24	1.51	55.7	9.75
	Silver	mg/kg	5	0			
		µg/l	27	2	2.34	60.1	31.22
	Sodium	mg/kg	5	5	461	7280	4432.20
		mg/L	28	28	70	2160	593.22
	Strontium	mg/kg	5	5	16	368	124.94
		µg/l	27	27	2.85	5190	1194.54
	Tellurium	mg/kg	3	0			
		µg/l	27	0			
	Thallium	mg/kg	5	0			
		µg/l	27	1	1.16	1.16	1.16
	Tin	mg/kg	5	4	1.64	17.6	7.58
		µg/l	27	23	0.373	246	23.27
	Titanium	mg/kg	5	5	8.07	52.4	29.73
		µg/l	27	26	7.73	769	191.47
	Vanadium	mg/kg	5	5	1.39	15.7	6.33
		µg/l	27	26	0.956	200	23.88
	Zinc	mg/kg	5	5	39.6	356	135.44
		µg/l	27	26	1.95	55100	2870.15

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration

Table C3: Phase 2 Data - Pig and Poultry Ash - Metals Analysis

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Suite A - Metals - (Liquid)	Extractable Calcium (Top Soil)	mg/l	59	59	88	12400	1055.48
	Extractable Magnesium (Top Soil)	mg/l	59	51	98.9	1750	542.15
	Extractable Potassium (Top Soil)	mg/l	59	59	6540	90900	25562.54
	Extractable Sodium (Top Soil)	mg/l	59	59	4440	29900	13773.90
Suite A - Metals - (Solids)	Aluminium	mg/kg	59	59	97.7	6350	1347.52
	Antimony	mg/kg	59	33	0.622	36.2	7.38
	Arsenic	mg/kg	59	5	0.624	1.09	0.83
	Barium	mg/kg	59	59	18.2	299	68.32
	Beryllium	mg/kg	59	39	0.0115	0.13	0.04
	Bismuth	mg/kg	59	5	1.07	4.17	2.25
	Boron	mg/kg	59	59	2.09	25.3	7.36
	Cadmium	mg/kg	59	4	0.155	0.331	0.24
	Calcium	mg/kg	59	59	543	415000	271399.03
	Chromium	mg/kg	59	59	3.51	258	25.35
	Cobalt	mg/kg	59	52	0.135	2.95	0.80
	Copper	mg/kg	59	59	12.8	1690	138.46
	Fluoride	mg/kg	54	49	80.2	787	408.44
	Fluoride, acid soluble	mg/kg	4	4	148	286	218.25
	Iron	mg/kg	56	47	1090	20100	3323.62
	Lead	mg/kg	59	40	0.718	705	59.62
	Lithium	mg/kg	59	43	1.02	4.11	1.91
	Magnesium	mg/kg	59	59	790	14100	8671.86
	Manganese	mg/kg	59	59	11.2	342	135.46
	Mercury	mg/kg	59	3	0.475	0.554	0.51
	Molybdenum	mg/kg	59	59	0.299	14.9	3.23
	Nickel	mg/kg	59	59	0.769	457	26.43
	Phosphorus	mg/kg	58	58	806	220000	145412.17
	Potassium	mg/kg	59	59	1100	81800	51455.93
	Selenium	mg/kg	59	0			
	Silver	mg/kg	59	0			
	Sodium	mg/kg	59	59	54.8	66300	32841.61
	Strontium	mg/kg	59	59	52.8	285	105.94
	Tellurium	mg/kg	59	0			
	Thallium	mg/kg	59	0			
	Tin	mg/kg	59	14	0.451	6.16	2.43
	Titanium	mg/kg	59	59	1.71	601	163.24
	Vanadium	mg/kg	59	59	0.4	4.03	1.85
	Zinc	mg/kg	59	59	153	2200	715.73

Table C3: Phase 2 Data - Pig and Poultry Ash - Metals Analysis

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration

Table C4: Phase 2 Data - Sewage Sludge - Metals Analysis

Treated Sludge

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Organo Metals	Dibutyltin	mg/kg	24	2	0.09	0.56	0.33
	Diphenyl Tin	mg/kg	24	0			
	Monobutyltin	mg/kg	24	0			
	Monophenyl Tin	mg/kg	24	0			
	Tetrabutyltin	mg/kg	24	0			
	Tributyltin	mg/kg	24	0			
	Triphenyltin	mg/kg	24	0			
Suite A - Metals - (Liquid)	Extractable Calcium (Top Soil)	mg/l	24	24	1010	44500	15302.08
	Extractable Magnesium (Top Soil)	mg/l	24	13	44.2	165	92.49
	Extractable Potassium (Top Soil)	mg/l	24	24	64	1150	420.38
	Extractable Sodium (Top Soil)	mg/l	24	23	94.5	274	190.83
Suite A - Metals - (Solids)	Aluminium	mg/kg	24	24	3710	15700	8346.25
	Antimony	mg/kg	24	21	2.95	22.8	7.20
	Arsenic	mg/kg	24	21	2.48	6.2	4.27
	Barium	mg/kg	24	24	140	277	181.17
	Beryllium	mg/kg	24	21	0.132	0.603	0.31
	Bismuth	mg/kg	24	24	1.98	8.88	4.33
	Boron	mg/kg	24	24	5.51	21.5	10.83
	Cadmium	mg/kg	24	23	0.0318	0.775	0.55
	Calcium	mg/kg	24	24	64200	219000	112804.17
	Chromium	mg/kg	24	24	13.7	39.2	21.51
	Cobalt	mg/kg	24	24	2.12	5.4	3.63
	Copper	mg/kg	24	24	65.4	193	115.29
	Fluoride, acid soluble	mg/kg	24	24		4780	1155.92
	Iron	mg/kg	24	24	11000	29600	17662.50
	Lead	mg/kg	24	24	34.1	104	47.04
	Lithium	mg/kg	24	1	1.57	1.57	1.57
	Magnesium	mg/kg	24	24	1680	2790	2078.75
	Manganese	mg/kg	24	24	186	690	364.50
	Mercury	mg/kg	24	10	0.151	4.15	0.77
	Molybdenum	mg/kg	24	24	2.01	4.77	3.29
	Nickel	mg/kg	24	24	10.5	19.2	14.48
	Phosphorus	mg/kg	24	24	1290	18400	13529.17
	Potassium	mg/kg	24	24	1070	2460	1467.92
	Selenium	mg/kg	24	17	1.02	3.45	1.86
	Silver	mg/kg	24	0			
	Sodium	mg/kg	24	24	360	1240	621.96
	Strontium	mg/kg	24	24	78.5	207	136.68
	Tellurium	mg/kg	24	2	1.05	1.29	1.17
	Thallium	mg/kg	24	0			
	Tin	mg/kg	24	24	15.4	37.1	21.48
	Titanium	mg/kg	24	24	9.17	84.7	47.05
	Vanadium	mg/kg	24	24	8.62	21.6	11.95
	Zinc	mg/kg	24	24	226	468	330.96

Untreated Sludge

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Suite A - Metals - (Solids)	Aluminium	mg/kg	24	24	4020	15600	7806.67
	Antimony	mg/kg	24	24	4.53	7.01	5.81
	Arsenic	mg/kg	24	24	2.9	7.51	4.80
	Barium	mg/kg	24	24	139	315	201.67
	Beryllium	mg/kg	24	24	0.239	0.753	0.34
	Bismuth	mg/kg	24	24	1.66	118	9.92
	Boron	mg/kg	24	24	6.94	17.7	11.41
	Cadmium	mg/kg	24	24	0.485	0.758	0.65
	Calcium	mg/kg	24	24	14600	72600	34508.33
	Chromium	mg/kg	24	24	16.7	32.8	19.99
	Cobalt	mg/kg	24	24	2.51	5.01	3.70
	Copper	mg/kg	24	24	118	263	176.67
	Iron	mg/kg	24	24	10800	40100	22191.67
	Lead	mg/kg	24	24	40	132	55.07
	Lithium	mg/kg	24	0			
	Magnesium	mg/kg	24	24	1680	4660	2550.00
	Manganese	mg/kg	24	24	150	859	278.88
	Mercury	mg/kg	24	12	0.274	2.02	0.62
	Molybdenum	mg/kg	24	24	2.56	5.18	3.91
	Nickel	mg/kg	24	24	13.7	22.1	16.02
	Phosphorus	mg/kg	24	24	7870	22800	15082.08
	Potassium	mg/kg	24	24	1000	4310	1819.17
	Selenium	mg/kg	24	24	1.76	4.21	2.78
	Silver	mg/kg	24	0			
	Sodium	mg/kg	24	24	344	2920	795.67
	Strontium	mg/kg	24	24	41	155	101.75
	Tellurium	mg/kg	24	1	1.28	1.28	1.28
	Thallium	mg/kg	24	1	0.888	0.888	0.89

Table C4: Phase 2 Data - Sewage Sludge - Metals Analysis

Treated Sludge

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
	Tin	mg/kg	24	24	19.8	54.1	27.30
	Titanium	mg/kg	24	24	8.29	97.7	54.60
	Vanadium	mg/kg	24	24	10.1	27.7	14.16
	Zinc	mg/kg	24	24	308	624	443.29

Lime

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Suite A - Metals - (Solids)	Aluminium	mg/kg	7	7	470	851	627.57
	Antimony	mg/kg	7	1	1.17	1.17	1.17
	Arsenic	mg/kg	7	1	0.68	0.68	0.68
	Barium	mg/kg	7	7	5.57	11	8.32
	Beryllium	mg/kg	7	6	0.0525	0.0978	0.08
	Bismuth	mg/kg	7	0			
	Boron	mg/kg	7	7	1.23	2.81	2.02
	Cadmium	mg/kg	7	7	0.0625	0.586	0.34
	Calcium	mg/kg	6	6	493000	755000	623000.00
	Chromium	mg/kg	7	5	3.93	5.96	4.74
	Cobalt	mg/kg	7	6	0.351	0.607	0.46
	Copper	mg/kg	7	5	1.5	3.74	2.61
	Iron	mg/kg	7	4	1520	2970	2232.50
	Lead	mg/kg	7	1	7.38	7.38	7.38
	Lithium	mg/kg	7	6	1.42	3.56	2.00
	Magnesium	mg/kg	6	6	1080	1740	1435.00
	Manganese	mg/kg	7	7	80.9	392	306.41
	Mercury	mg/kg	7	0			
	Molybdenum	mg/kg	7	5	0.116	0.354	0.22
	Nickel	mg/kg	7	7	1.39	3.36	2.44
	Phosphorus	mg/kg	7	7	12.1	321	139.59
	Potassium	mg/kg	6	6	166	496	307.17
	Selenium	mg/kg	7	0			
	Silver	mg/kg	7	0			
	Sodium	mg/kg	6	6	78.6	1780	417.60
	Strontium	mg/kg	7	7	276	846	393.14
	Tellurium	mg/kg	7	2	1.02	1.3	1.16
	Thallium	mg/kg	7	1	0.761	0.761	0.76
	Tin	mg/kg	7	0			
	Titanium	mg/kg	6	6	1.5	19.2	8.42
	Vanadium	mg/kg	7	7	1	6.05	4.20
	Zinc	mg/kg	7	7	3.04	16.3	9.04

Table C5: Phase 1 Data - All Stackable Waste - Dioxins, Furans, Dioxin-like PCBs and PAHs

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Dioxins	1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	ng/kg	18	17	15	5600	839.76
	1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	ng/kg	18	14	8.6	520	95.19
	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	ng/kg	18	1	2.6	2.6	2.60
	1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	ng/kg	18	5	5.5	10	7.12
	1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	ng/kg	18	4	2.8	6.5	4.33
	1,2,3,7,8-Pentachlorodibenzo-p-dioxin	ng/kg	18	1	4.5	4.5	4.50
	2,3,7,8-Tetrachlorodibenzo-p-dioxin	ng/kg	18	0			
Furans	1,2,3,4,6,7,8,9-Octachlorodibenzofuran	ng/kg	18	8	16	140	61.38
	1,2,3,4,6,7,8-Heptachlorodibenzofuran	ng/kg	18	7	5.7	52	28.90
	1,2,3,4,7,8,9-Heptachlorodibenzofuran	ng/kg	18	2	5.9	22	13.95
	1,2,3,4,7,8-Hexachlorodibenzofuran	ng/kg	19	3	4.1	31	14.57
	1,2,3,6,7,8-Hexachlorodibenzofuran	ng/kg	18	3	3.4	11	6.83
	1,2,3,7,8,9-Hexachlorodibenzofuran	ng/kg	18	0			
	1,2,3,7,8-Pentachlorodibenzofuran	ng/kg	18	2	3.4	5.7	4.55
	2,3,4,6,7,8-Hexachlorodibenzofuran	ng/kg	18	2	4.4	6.2	5.30
	2,3,4,7,8-Pentachlorodibenzofuran	ng/kg	18	2	4.2	6	5.10
	2,3,7,8-Tetrachlorodibenzofuran	ng/kg	18	3	2.8	6.5	4.27
PCBs	Heptachlorobiphenyl, 2,3,3,4,4,5,5- (PCB 189)	ng/kg	20	1	150	150	150.00
	Hexachlorobiphenyl, 2,3,3,4,4,5- (PCB 156)	ng/kg	20	5	130	2900	722.00
	Hexachlorobiphenyl, 2,3,3,4,4,5- (PCB 157)	ng/kg	20	1	330	330	330.00
	Hexachlorobiphenyl, 2,3,4,4,5,5- (PCB 167)	ng/kg	20	5	170	1300	482.00
	Hexachlorobiphenyl, 3,3,4,4,5,5- (PCB 169)	ng/kg	20	0			
	Pentachlorobiphenyl, 2,3,3,4,4- (PCB 105)	ng/kg	20	14	140	49000	3817.14
	Pentachlorobiphenyl, 2,3,4,4,5- (PCB 114)	ng/kg	20	1	2800	2800	2800.00
	Pentachlorobiphenyl, 2,3',4,4',5- (PCB 118)	ng/kg	20	17	160	54000	3758.24
	Pentachlorobiphenyl, 2,3,4,4,5- (PCB 123)	ng/kg	20	1	1100	1100	1100.00
	Pentachlorobiphenyl, 3,3,4,4,5- (PCB 126)	ng/kg	20	1	260	260	260.00
	Tetrachlorobiphenyl, 3,3,4,4- (PCB 77)	ng/kg	20	8	180	69000	9010.00
	Tetrachlorobiphenyl, 3,4,4,5- (PCB 81)	ng/kg	20	1	2200	2200	2200.00
Suite A - Polyaromatic Hydrocarbons	Acenaphthene	mg/kg	65	16	0.0198	1.6	0.22
	Acenaphthylene	mg/kg	65	6	0.0335	27.3	8.74
	Anthracene	mg/kg	65	20	0.0245	38.1	3.47
	Benz(a)anthracene	mg/kg	65	20	0.0236	32.7	3.66
	Benzo(a)pyrene	mg/kg	65	20	0.0188	23.3	2.75
	Benzo(b)fluoranthene	mg/kg	65	21	0.0198	28.7	3.07
	Benzo(g,h,i)perylene	mg/kg	65	17	0.0846	11.5	1.72
	Benzo(k)fluoranthene	mg/kg	65	16	0.0721	14.1	2.19
	Chrysene	mg/kg	65	21	0.0156	24.8	2.98
	Coronene	mg/kg	33	0			
	Dibenzo(a,h)anthracene	mg/kg	65	7	0.075	3.49	1.06
	Fluoranthene	mg/kg	65	31	0.027	159	9.67
	Fluorene	mg/kg	65	19	0.027	16.6	1.52
	Indeno(1,2,3-cd)pyrene	mg/kg	64	16	0.0823	11.2	1.91
	Naphthalene	mg/kg	95	19	0.0171	17.7	2.09
	PAH, Total Detected USEPA 16	mg/kg	32	25	0.156	647	31.63
	PAH, Total Detected USEPA 16 + Coronene	mg/kg	33	26	0.156	647	30.49
	Phenanthrene	mg/kg	64	32	0.045	131	7.55
	Pyrene	mg/kg	64	33	0.0251	107	6.45

Table C6: Phase 1 Data - All Non-Stackable Waste - Dioxins, Furans, Dioxin-like PCBs and PAHs

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Dioxins	1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	mg/kg	4	4	0.000025	0.00059	0.000226
	1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	mg/kg	4	3	0.0000068	0.000046	0.000026
	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	mg/kg	4	0			
	1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	mg/kg	4	1	0.0000029	0.0000029	0.000003
	1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	mg/kg	4	0			
	1,2,3,7,8-Pentachlorodibenzo-p-dioxin	mg/kg	4	0			
	2,3,7,8-Tetrachlorodibenzo-p-dioxin	mg/kg	4	0			
Furans	1,2,3,4,6,7,8,9-Octachlorodibenzofuran	mg/kg	4	1	0.000015	0.000015	0.000015
	1,2,3,4,6,7,8-Heptachlorodibenzofuran	mg/kg	4	1	0.0000062	0.0000062	0.000006
	1,2,3,4,7,8,9-Heptachlorodibenzofuran	mg/kg	4	0			
	1,2,3,4,7,8-Hexachlorodibenzofuran	mg/kg	4	0			
	1,2,3,6,7,8-Hexachlorodibenzofuran	mg/kg	4	0			
	1,2,3,7,8,9-Hexachlorodibenzofuran	mg/kg	4	0			
	1,2,3,7,8-Pentachlorodibenzofuran	mg/kg	4	0			
	2,3,4,6,7,8-Hexachlorodibenzofuran	mg/kg	4	0			
	2,3,4,7,8-Pentachlorodibenzofuran	mg/kg	4	0			
	2,3,7,8-Tetrachlorodibenzofuran	mg/kg	4	0			
PCBs	Heptachlorobiphenyl, 2,3,3,4,4,5,5- (PCB 189)	mg/kg	4	0			
		ng/l	23	0			
	Hexachlorobiphenyl, 2,3,3,4,4,5- (PCB 156)	mg/kg	4	3	0.00013	0.00016	0.00014
		ng/l	23	6	0.27	0.43	0.34
	Hexachlorobiphenyl, 2,3,3,4,4,5- (PCB 157)	mg/kg	4	0			
		ng/l	23	0			
	Hexachlorobiphenyl, 2,3,4,4,5,5- (PCB 167)	mg/kg	4	0			
		ng/l	23	5	0.11	0.73	0.42
	Hexachlorobiphenyl, 3,3,4,4,5,5- (PCB 169)	mg/kg	4	0			
		ng/l	23	0			
	Pentachlorobiphenyl, 2,3,3,4,4- (PCB 105)	mg/kg	4	3	0.00012	0.0007	0.00037
		ng/l	23	11	0.1	0.86	0.52
	Pentachlorobiphenyl, 2,3,4,4,5- (PCB 114)	mg/kg	4	0			
		ng/l	23	0			
	Pentachlorobiphenyl, 2,3',4,4',5- (PCB 118)	mg/kg	4	4	0.00021	0.0012	0.00064
		ng/l	23	15	0.13	2.9	1.11
	Pentachlorobiphenyl, 2,3,4,4,5- (PCB 123)	mg/kg	4	0			
		ng/l	23	1	0.2	0.2	0.20
	Pentachlorobiphenyl, 3,3,4,4,5- (PCB 126)	mg/kg	4	0			
		ng/l	23	0			
	Tetrachlorobiphenyl, 3,3,4,4- (PCB 77)	mg/kg	4	1	0.0011	0.0011	0.00110
		ng/l	23	3		0.23	0.12
	Tetrachlorobiphenyl, 3,4,4,5- (PCB 81)	mg/kg	4	0			
		ng/l	23	0			
Suite A - Polyaromatic Hydrocarbons	Acenaphthene	mg/kg	10	1	0.376	0.376	0.38
		µg/l	63	11	0.178	264	27.06
	Acenaphthylene	mg/kg	10	0			
		µg/l	63	11	0.0281	226	25.19
	Anthracene	mg/kg	10	0			
		µg/l	63	13	0.228	250	27.61
	Benz(a)anthracene	mg/kg	10	0			
		µg/l	63	8	0.439	315	74.66
	Benzo(a)pyrene	mg/kg	10	0			
		µg/l	63	19	0.0258	338	32.03
	Benzo(b)fluoranthene	mg/kg	10	0			
		µg/l	63	12	0.173	504	70.60
	Benzo(g,h,i)perylene	mg/kg	10	0			
		µg/l	63	13	0.0968	428	46.61
	Benzo(k)fluoranthene	mg/kg	10	1	0.211	0.211	0.21
		µg/l	63	7	0.662	348	65.64
	Chrysene	mg/kg	10	0			
		µg/l	63	14	0.0389	311	41.79
	Coronene	mg/kg	5	0			
	Dibenzo(a,h)anthracene	mg/kg	10	0			
		µg/l	63	10	0.0419	381	43.32
	Fluoranthene	mg/kg	10	0			
		µg/l	63	21	0.0774	381	54.17
	Fluorene	mg/kg	10	0			
		µg/l	63	15	0.106	265	23.05
	Indeno(1,2,3-cd)pyrene	mg/kg	10	0			
		µg/l	63	11	0.062	487	56.71
	Naphthalene	mg/kg	15	1	0.314	0.314	0.31
		µg/l	97	11	0.428	381	56.51
	PAH, Total Detected USEPA 16	mg/kg	5	3	0.211	0.436	0.34
		µg/l	32	17	0.428	5480	511.65
	PAH, Total Detected USEPA 16 + Coronene	mg/kg	5	3	0.211	0.436	0.34
	Phenanthrene	mg/kg	10	0			
		µg/l	63	24	0.219	296	32.45
	Pyrene	mg/kg	10	1	0.436	0.436	0.44
		µg/l	63	19	0.0991	345	44.48

Table C7: Phase 2 Data - Pig and Poultry Ash - Dioxins, Furans, Dioxin-like PCBs and PAHs

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Dioxins	1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	ng/kg	59	56	0.31	20.9	1.64
	1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	ng/kg	59	56	0.104	6.08	0.78
	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	ng/kg	59	8	0.0606	0.522	0.20
	1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	ng/kg	59	22	0.0439	0.695	0.25
	1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	ng/kg	59	12	0.0657	0.558	0.23
	1,2,3,7,8-Pentachlorodibenzo-p-dioxin	ng/kg	59	4	0.144	1.01	0.58
	2,3,7,8-Tetrachlorodibenzo-p-dioxin	ng/kg	59	4	0.0959	1.24	0.55
Furans	1,2,3,4,6,7,8,9-Octachlorodibenzofuran	ng/kg	59	27	0.0892	5.49	0.73
	1,2,3,4,6,7,8-Heptachlorodibenzofuran	ng/kg	59	53	0.0595	9.56	0.79
	1,2,3,4,7,8,9-Heptachlorodibenzofuran	ng/kg	59	21	0.0332	0.473	0.17
	1,2,3,4,7,8-Hexachlorodibenzofuran	ng/kg	59	29	0.0572	3.86	0.55
	1,2,3,6,7,8-Hexachlorodibenzofuran	ng/kg	59	25	0.0522	3.79	0.50
	1,2,3,7,8,9-Hexachlorodibenzofuran	ng/kg	59	21	0.0632	0.341	0.14
	1,2,3,7,8-Pentachlorodibenzofuran	ng/kg	59	20	0.0989	12.5	1.18
	2,3,4,6,7,8-Hexachlorodibenzofuran	ng/kg	59	29	0.051	5.91	0.63
	2,3,4,7,8-Pentachlorodibenzofuran	ng/kg	59	19	0.0575	14.9	1.43
	2,3,7,8-Tetrachlorodibenzofuran	ng/kg	59	25	0.116	46.3	3.88
PCBs	Heptachlorobiphenyl, 2,3,3,4,4,5,5- (PCB 189)	ng/kg	59	40	0.054	0.892	0.19
	Hexachlorobiphenyl, 2,3,3,4,4,5- (PCB 156)	ng/kg	59	58	0.0851	2.18	0.47
	Hexachlorobiphenyl, 2,3,3,4,4,5- (PCB 157)	ng/kg	59	43	0.0161	1.47	0.20
	Hexachlorobiphenyl, 2,3,4,4,5,5- (PCB 167)	ng/kg	59	50	0.0411	0.866	0.20
	Hexachlorobiphenyl, 3,3,4,4,5,5- (PCB 169)	ng/kg	59	31	0.0228	1.95	0.19
	Pentachlorobiphenyl, 2,3,3,4,4- (PCB 105)	ng/kg	59	59	0.209	7.94	1.67
	Pentachlorobiphenyl, 2,3,4,4,5- (PCB 114)	ng/kg	59	26	0.057	0.854	0.27
	Pentachlorobiphenyl, 2,3',4,4',5- (PCB 118)	ng/kg	59	59	0.664	16.4	3.55
	Pentachlorobiphenyl, 2,3,4,4,5- (PCB 123)	ng/kg	59	31	0.0812	0.613	0.22
	Pentachlorobiphenyl, 3,3,4,4,5- (PCB 126)	ng/kg	59	35	0.0861	18.2	1.03
	Tetrachlorobiphenyl, 3,3,4,4- (PCB 77)	ng/kg	59	59	0.366	86	4.35
	Tetrachlorobiphenyl, 3,4,4,5- (PCB 81)	ng/kg	59	35	0.0357	3.72	0.39
Suite A - Polyaromatic Hydrocarbons	Acenaphthene	mg/kg	58	7	0.00829	0.0715	0.04
	Acenaphthylene	mg/kg	58	14	0.0248	0.658	0.24
	Anthracene	mg/kg	58	21	0.017	0.229	0.08
	Benz(a)anthracene	mg/kg	58	19	0.0148	0.183	0.07
	Benzo(a)pyrene	mg/kg	58	12	0.0153	0.0825	0.04
	Benzo(b)fluoranthene	mg/kg	58	13	0.0184	0.297	0.09
	Benzo(g,h,i)perylene	mg/kg	58	12	0.0283	0.107	0.06
	Benzo(k)fluoranthene	mg/kg	58	4	0.0209	0.057	0.04
	Chrysene	mg/kg	58	23	0.0127	0.25	0.07
	Dibenzo(a,h)anthracene	mg/kg	58	3	0.0246	0.0287	0.03
	Fluoranthene	mg/kg	58	28	0.0197	0.411	0.13
	Fluorene	mg/kg	58	18	0.011	0.382	0.10
	Indeno(1,2,3-cd)pyrene	mg/kg	58	4	0.0282	0.0731	0.06
	Naphthalene	mg/kg	58	43	0.00955	5.08	0.46
	PAH, Total Detected USEPA 16	mg/kg	58	30	0.12	7.25	1.70
	Phenanthrene	mg/kg	58	40	0.0169	1.35	0.29
	Pyrene	mg/kg	58	29	0.0165	0.373	0.13

Table C8: Phase 2 Data - Sewage Sludge - Dioxins, Furans, Dioxin-like PCBs and PAHs

Treated Sludge

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Dioxins	1,2,3,4,6,7,8,9-Octachlorodibenzo-p-dioxin	ng/kg	24	24	187	1170	568.46
	1,2,3,4,6,7,8-Heptachlorodibenzo-p-dioxin	ng/kg	24	24	22.6	184	77.43
	1,2,3,4,7,8-Hexachlorodibenzo-p-dioxin	ng/kg	24	24	0.312	1.09	0.63
	1,2,3,6,7,8-Hexachlorodibenzo-p-dioxin	ng/kg	24	24	1.16	8.67	3.04
	1,2,3,7,8,9-Hexachlorodibenzo-p-dioxin	ng/kg	24	24	0.865	4.05	1.74
	1,2,3,7,8-Pentachlorodibenzo-p-dioxin	ng/kg	24	18	0.412	1.01	0.69
	2,3,7,8-Tetrachlorodibenzo-p-dioxin	ng/kg	24	3	0.148	0.268	0.21
Furans	1,2,3,4,6,7,8,9-Octachlorodibenzofuran	ng/kg	24	24	10.8	36.5	18.92
	1,2,3,4,6,7,8-Heptachlorodibenzofuran	ng/kg	24	24	7.1	44.7	13.57
	1,2,3,4,7,8,9-Heptachlorodibenzofuran	ng/kg	24	23	0.453	2.21	1.01
	1,2,3,4,7,8-Hexachlorodibenzofuran	ng/kg	24	24	0.839	6.01	2.24
	1,2,3,6,7,8-Hexachlorodibenzofuran	ng/kg	24	24	0.612	2.54	1.45
	1,2,3,7,8,9-Hexachlorodibenzofuran	ng/kg	24	15	0.134	1.74	0.35
	1,2,3,7,8-Pentachlorodibenzofuran	ng/kg	24	23	0.584	34.2	2.75
	2,3,4,6,7,8-Hexachlorodibenzofuran	ng/kg	24	24	1.1	3.27	1.98
	2,3,4,7,8-Pentachlorodibenzofuran	ng/kg	24	24	0.579	20.7	2.33
	2,3,7,8-Tetrachlorodibenzofuran	ng/kg	24	23	1.1	55.4	7.21
PCBs	Heptachlorobiphenyl, 2,3,3,4,4,5,5- (PCB 189)	ng/kg	24	24	6.62	62.6	14.36
	Hexachlorobiphenyl, 2,3,3,4,4,5- (PCB 156)	ng/kg	24	24	61	317	133.45
	Hexachlorobiphenyl, 2,3,3,4,4,5- (PCB 157)	ng/kg	24	24	13.5	66.1	27.35
	Hexachlorobiphenyl, 2,3,4,4,5,5- (PCB 167)	ng/kg	24	24	19.3	105	47.01
	Hexachlorobiphenyl, 3,3,4,4,5,5- (PCB 169)	ng/kg	24	24	0.546	1.84	0.91
	Pentachlorobiphenyl, 2,3,3,4,4- (PCB 105)	ng/kg	24	24	127	992	321.75
	Pentachlorobiphenyl, 2,3,4,4,5- (PCB 114)	ng/kg	24	24	11.5	54.6	21.48
	Pentachlorobiphenyl, 2,3',4,4',5- (PCB 118)	ng/kg	24	24	301	2440	815.46
	Pentachlorobiphenyl, 2,3,4,4,5- (PCB 123)	ng/kg	24	24	6.23	35.7	15.02
	Pentachlorobiphenyl, 3,3,4,4,5- (PCB 126)	ng/kg	24	24	2.43	5.77	4.22
	Tetrachlorobiphenyl, 3,3,4,4- (PCB 77)	ng/kg	24	24	50.6	604	130.00
	Tetrachlorobiphenyl, 3,4,4,5- (PCB 81)	ng/kg	24	24	0.529	4.63	2.75
Suite A - Polyaromatic Hydrocarbons	Acenaphthene	mg/kg	69	29	0.0547	3.47	0.56
	Acenaphthylene	mg/kg	69	10	0.0414	0.267	0.12
	Anthracene	mg/kg	69	37	0.0704	7.42	0.70
	Benz(a)anthracene	mg/kg	69	43	0.209	13.6	1.44
	Benzo(a)pyrene	mg/kg	69	44	0.218	12.6	1.46
	Benzo(b)fluoranthene	mg/kg	69	45	0.215	12.6	1.52
	Benzo(g,h,i)perylene	mg/kg	69	42	0.177	9.06	1.06
	Benzo(k)fluoranthene	mg/kg	69	43	0.0978	6.13	0.71
	Chrysene	mg/kg	69	45	0.157	12.1	1.21
	Dibenzo(a,h)anthracene	mg/kg	69	29	0.0761	2.11	0.33
	Fluoranthene	mg/kg	69	46	0.421	31	2.78
	Fluorene	mg/kg	69	33	0.0627	2.15	0.34
	Indeno(1,2,3-cd)pyrene	mg/kg	69	42	0.129	7.37	0.86
	Naphthalene	mg/kg	92	55	0.0977	6.18	1.79
	PAH, Total Detected USEPA 16	mg/kg	45	45	3	171	18.80
	Phenanthrene	mg/kg	69	43	0.252	27.5	2.33
	Pyrene	mg/kg	69	45	0.332	26.1	2.57

Table C9: Phase 1 Data - All Stackable Waste - Sample Physical Properties

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Asbestos Suite - Asbestos	Amosite (Brown) Asbestos	-	29	0			
	Chrysotile (White) Asbestos	-	29	0			
	Crocidolite (Blue) Asbestos	-	29	0			
	Fibrous Actinolite	-	29	0			
	Fibrous Anthophyllite	-	29	0			
	Fibrous Tremolite	-	29	0			
	Non-Asbestos Fibre	-	29	19			
Bacteria Suite - Microbiological	Escherichia coli	MPN/g	21	16	1	20100	5068.62
	Salmonella	-	26	6			
	Total Coliforms	MPN/g	18	17	201	40100	5086.12
Suite A - Carbon	Carbon	% w / w	2	2	2.5	27.1	14.80
	Organic Carbon, Total	%	27	27	0.784	36.7	13.78
	Organic Matter, Total	%	32	31	1.35	63.3	23.10
Suite A - Inorganics	pH	pH Units	29	29	5.33	12.9	7.74
	Alkalinity, Carbonate as CaCO3	mg/kg	1	0			
	Ammoniacal Nitrogen as N	mg/kg	33	17	40.6	8500	1763.78
	Bromide, 2:1 water soluble	mg/kg	14	10	0.51	3240	330.53
	C:N Ratio	-	2	2	19.1	31.1	25.10
	C:N Ratio Calculated	-	18	18	4.21	59.2	27.97
	Chloride (soluble)	mg/kg	12	12	9.81	142000	12137.76
	Conductivity @ 20 deg.C	mS/cm	19	19	1.73	102	9.13
	Neutralising value	%	33	33	1.4	41.7	15.71
	Nitrate as N, 2:1 water soluble	mg/kg	14	11	0.268	359	36.22
	Nitrite (soluble) as N	mg/kg	14	12	0.0494	52.9	6.26
	Nitrogen, Total	% Dry Weight	30	30	0.16	4.86	1.03
	Phosphate (Bicarbonate Extractable) as PO4	mg/l	24	24	0.302	326	59.16
	Phosphate (ortho) as PO4	mg/kg	12	5	1.26	182	45.71
	Sulphate, Total	mg/kg	33	33	362	428000	27798.03
	Sulphide, Easily liberated	mg/kg	33	8	28.6	1860	339.09
	Total Oxidised Nitrogen as NO3	mg/kg	1	1	28.5	28.5	28.50
	Total Sulphur	-	32	32	0.0121	14.3	0.95
	Water Soluble Sulphate as SO4 2:1 Extract	g/l	11	10	0.0871	3.92	0.93
Suite A - Sample Description	Moisture Content Ratio (% of as received sample)	%	35	35	5.7	76	46.55
	Soil Density	-	33	33	0.17	1.06	0.56
Suite A - Subcontracted: Organics	Anaerobic Digestate*	-	16	16	1	1	1.00
	Dry Matter (DM) content	% w/w	19	19	14.6	84.1	48.49
	Iodide	mg/kg	31	1	12	12	12.00
	Iodine	mg/kg	31	0			
	PSD PAS100	-	15	15			
	Total glass, metal and "other" fragments	% w/w	20	20		0.585	0.09
	Total plastic	% w/w	20	20		1.043	0.11
	Total stones >5mm in size	% w/w	19	19		10.512	1.11

Table C10: Phase 1 Data - All Non-Stackable Waste - Sample Physical Properties

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Asbestos Suite - Asbestos	Amosite (Brown) Asbestos	-	2	0			
	Chrysotile (White) Asbestos	-	2	0			
	Crocidolite (Blue) Asbestos	-	2	0			
	Fibrous Actinolite	-	2	0			
	Fibrous Anthophyllite	-	2	0			
	Fibrous Tremolite	-	2	0			
	Non-Asbestos Fibre	-	2	2			
Bacteria Suite - Microbiological	Escherichia coli	MPN/g	37	34	1	20100	6173.85
	Salmonella	-	37	20	1	1	1.00
	Total Coliforms	MPN/g	32	31	3	40100	10370.65
Suite A - Carbon	Organic Carbon, Total	%	3	3	8.28	30.4	21.83
		mg/L	31	31	274	12800	4296.74
	Organic Matter, Total	%	5	5	14.3	52.4	33.74
Suite A - Inorganics	pH	pH Units	39	39	3.53	12.5	7.02
	Ammoniacal Nitrogen as N	mg/kg	5	4	2300	14300	8462.50
		mg/L	20	20	5.23	3620	677.22
	Conductivity @ 20 deg.C	mS/cm	33	33	0.562	22.1	8.29
	Neutralising value	%	5	5	2.24	36.7	13.44
	Nitrogen, Total	% Dry Weight	5	5	0.25	6.77	2.84
		mg/L	40	40	0.408	5920	1020.70
	Phosphate (ortho) as PO4	mg/L	31	31	0.088	1020	179.98
	Sulphate, Total	mg/kg	5	5	1310	22800	7276.00
		mg/L	32	21	2.3	1380	269.82
	Sulphide, Easily liberated	mg/kg	5	2	313	3980	2146.50
	Total Oxidised Nitrogen as NO3	mg/L	10	1	167	167	167.00
Suite A - Sample Description	Moisture Content Ratio (% of as received sample)	-	1	1	93	93	93.00
		%	5	5	54	90	79.40
	Soil Density	-	5	5	0.17	0.7	0.48

Table C11: Phase 2 Data - Pig and Poultry Ash - Sample Physical Properties

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Suite A - Carbon	Organic Carbon, Total	%	58	52	0.261	32.1	**4.76**
	Organic Matter, Total	%	58	52	0.45	55.3	**8.20**
Suite A - Inorganics	pH	pH Units	58	58	9.36	13.1	**11.68**
	Ammoniacal Nitrogen as N	mg/kg	58	19	12.7	320	**110.77**
	Conductivity @ 20 deg.C	mS/cm	58	58	13.2	57.4	**31.56**
	Neutralising value	%	58	58	2.24	19.3	**7.40**
	Nitrogen, Total	% Dry Weight	58	57	0.06	2.41	**0.66**
	Phosphate (Bicarbonate Extractable) as mg/l P	mg/l	59	59	2.88	15100	**5123.00**
	Sulphur	%	58	58	0.023	1.72	**0.44**
Suite A - Sample Description	Moisture Content Ratio (% of as received sample)	%	59	59	-0.3	16	**2.01**
	Soil Density	-	59	59	0.4	1.23	**0.72**
Suite A - Subcontracted: Organics	Iodide	mg/kg	58	0			
	Iodine	mg/kg	58	0			
	PSD PAS100	-	58	58			
	Total glass, metal and "other" fragments	% w/w	58	58		0.24	**0.01**
	Total plastic	% w/w	58	58		0.09	**0.00**
	Total stones >4mm in size	% w/w	58	58		1.17	**0.06**

Table C12: Phase 2 Data - Sewage Sludge - Sample Physical Properties

Treated Sludge

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Bacteria Suite - Microbiological	Escherichia coli	MPN/g	47	28	20	20100	**3008.57**
	Salmonella	-	41	5			
	Total Coliforms	MPN/g	47	27	87	165000	**26725.04**
Suite A - Carbon	Organic Carbon, Total	%	24	24	9.25	33.5	**22.69**
	Organic Matter, Total	%	24	24	15.9	57.8	**39.12**
Suite A - Inorganics	pH	pH Units	47	47	7.12	12.7	**10.18**
	Ammoniacal Nitrogen as N	mg/kg	24	24	689	11400	**4497.88**
	Conductivity @ 20 deg.C	mS/cm	16	16	3.67	11.3	**7.91**
	Neutralising value	%	24	24	3.08	20.5	**10.42**
	Nitrogen, Total	% Dry Weight	24	24	0.18	3.39	**2.50**
	Phosphate (Bicarbonate Extractable) as mg/l P	mg/l	9	9	247	470	**346.00**
	Sulphur	%	24	23	0.0681	0.779	**0.29**
Suite A - Sample Description	Moisture Content Ratio (% of as received sample)	%	45	45	57	78	**68.56**
	Soil Density	-	24	24	0.14	0.7	**0.41**
Suite A - Subcontracted: Organics	Iodide	mg/kg	24	0			
	Iodine	mg/kg	24	0			
	PSD PAS100	-	27	27			
	Total glass, metal and "other" fragments	% w/w	27	27		0.25	**0.02**
	Total plastic	% w/w	27	27		0.06	**0.00**
	Total stones >4mm in size	% w/w	27	27		0.17	**0.01**

Untreated Sludge

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Bacteria Suite - Microbiological	Escherichia coli	MPN/g	24	24	13700	2010000	**453312.50**
	Salmonella	-	24	23			
	Total Coliforms	MPN/g	24	24	20100	2010000	**1208941.67**
Suite A - Inorganics	pH	pH Units	24	24	6.65	8.46	**7.27**
Suite A - Sample Description	Moisture Content Ratio (% of as received sample)	%	24	24	65	79	**72.67**

Table C13: Phase 1 Data - All Stackable Waste - Organic Compounds

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Other Miscellaneous	Benzophenone	mg/kg	1	1	7.4	7.4	7.40
	Cholesterol	mg/kg	1	1	212	212	212.00
	Dihydrotrimethylpurinedione	µg/kg	1	1	79300	79300	79300
	Diisopropylnaphthalene group	mg/kg	3	3	22.8	51.4	32.83
	Diisopropylnaphthalene, isomer 1	mg/kg	2	2	13.8	15.3	14.55
	Diisopropylnaphthalene, isomer 2	mg/kg	2	2	18.8	20.4	19.60
	Diisopropylnaphthalene, isomer 3	mg/kg	2	2	8.37	11	9.69
	Diisopropylnaphthalene, isomer 4	mg/kg	2	2	11.7	12.3	12.00
	Diisopropylnaphthalene, isomer 5	mg/kg	2	2	3.05	4.12	3.59
	Hydrocarbon Range C8-C30	µg/kg	1	1	251000	251000	251000
	Indole	mg/kg	1	1	1.44	1.44	1.44
	Isomer of Phthalate	mg/kg	1	1	102	102	102.00
	Isomer of Phthalate 2	mg/kg	1	1	42	42	42.00
	Isomer of Phthalate 3	mg/kg	1	1	46.8	46.8	46.80
	Methane sulfonamide	mg/kg	1	1	3.03	3.03	3.03
	Octadecenoic Acid, Isomer	mg/kg	1	1	125	125	125.00
	Octadecenoic Acid, Isomer 1	mg/kg	1	1	53.6	53.6	53.60
	Trimethyl methylethyl octahydro phenanthrenol	µg/kg	1	1	2990	2990	2990.00
	Unknown, possible Cholestanol	µg/kg	1	1	318000	318000	318000
Suite B - Combined Pesticides / Herbicides	Aldrin	mg/kg	31	0			
	alpha-Hexachlorocyclohexane (HCH)	mg/kg	31	0			
	Azinphos-methyl	mg/kg	31	0			
	beta-Hexachlorocyclohexane (HCH)	mg/kg	31	0			
	Diazinon	mg/kg	31	0			
	Dichlorvos	mg/kg	31	0			
	Dieldrin	mg/kg	31	0			
	Disulfoton	mg/kg	31	0			
	Endosulphan I	mg/kg	31	0			
	Endosulphan II	mg/kg	31	0			
	Endosulphan sulphate	mg/kg	31	0			
	Endrin	mg/kg	31	0			
	Ethion	mg/kg	31	0			
	Fenitrothion	mg/kg	31	0			
	gamma-Hexachlorocyclohexane (HCH / Lindane)	mg/kg	31	0			
	Heptachlor	mg/kg	31	0			
	Heptachlor epoxide	mg/kg	31	0			
	Malathion	mg/kg	31	0			
	Methyl parathion	mg/kg	31	4	1.58	1.97	1.72
	Mevinphos	mg/kg	31	0			
	o,p'-DDD (TDE)	mg/kg	31	0			
	o,p-DDE	mg/kg	31	0			
	o,p-DDT	mg/kg	31	0			
	o,p-Methoxychlor	mg/kg	31	0			
	p,p-DDE	mg/kg	31	0			
	p,p-DDT	mg/kg	31	0			
	p,p-Methoxychlor	mg/kg	31	0			
	p,p-TDE (DDD)	mg/kg	31	0			
	Parathion	mg/kg	31	0			
	Phorate	mg/kg	31	0			
Suite B - Extractable Petroleum Hydrocarbons	EPH Range >C10 - C40	mg/kg	31	31	62.4	17000	4100
	Interpretation	-	17	17	1	1	1.00
Suite B - Miscellaneous Organics	3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctane-1-sulfonic acid	mg/kg	30	0			
	Branched PFOS	mg/kg	12	0			
	PFBA (Perfluoro-n-butanoic acid) 357-22-44	mg/kg	30	0			
	PFBS (Perfluoro-1-butanesulfonate) 375-73-5	mg/kg	30	0			
	PFDA (Perfluoro-n-decanoic acid) 335-76-2	mg/kg	30	0			
	PFDoA (Perfluoro-n-dodecanoic acid) 307-55-1	mg/kg	30	0			
	PFHpA (Perfluoro-n-heptanoic acid) 375-85-9	mg/kg	30	0			
	PFHpS (Perfluoro-1-heptanesulfonate) 375-92-8	mg/kg	30	0			
	PFHxA (Perfluoro-n-hexanoic acid) 307-24-4	mg/kg	30	0			
	PFHxS (Perfluoro-1-hexanesulfonate) 355-46-4	mg/kg	30	0			
	PFNA (Perfluoro-n-nonanoic acid) 375-95-1	mg/kg	30	0			
	PFOA (Perfluoro-n-octanoic acid) 335-67-1	mg/kg	30	0			
	PFOS	mg/kg	12	0			
	PFOS (Perfluoro-1-octanesulfonate) 1763-23-1	mg/kg	30	0			
	PFOSA (Perfluoro-octanesulfonamide) 754-91-6	mg/kg	12	0			
	PFPA (Perfluoro-n-pentanoic acid) 2706-90-3	mg/kg	30	0			
	PFUnA (Perfluoro-n-undecanoic acid) 2508-94-8	mg/kg	30	0			
Suite B - Semi-Volatile Organic Compounds	1,2,4-Trichlorobenzene	mg/kg	63	0			
	1,2-Dichlorobenzene	mg/kg	63	0			
	1,3-Dichlorobenzene	mg/kg	63	0			
	1,4-Dichlorobenzene	mg/kg	63	0			
	2,3,4,6-Tetrachlorophenol (TIC)	-	32	0			
	2,4,5-Trichlorophenol	mg/kg	32	0			
	2,4,6-Trichlorophenol	mg/kg	32	0			
	2,4-Dichlorophenol	mg/kg	32	0			
	2,4-Dimethylphenol	mg/kg	32	0			
	2,4-Dinitrotoluene	mg/kg	32	0			
	2,6-Dichlorophenol (TIC)	-	32	0			
	2,6-Dinitrotoluene	mg/kg	32	0			
	2-Chloronaphthalene	mg/kg	32	0			
	2-Chlorophenol	mg/kg	32	0			
	2-Methylnaphthalene	mg/kg	32	1	2.61	2.61	2.61
	2-Methylphenol	mg/kg	32	0			

Table C13: Phase 1 Data - All Stackable Waste - Organic Compounds

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
	2-Nitroaniline	mg/kg	32	0			
	2-Nitrophenol	mg/kg	32	0			
	3-Nitroaniline	mg/kg	32	0			
	4-Bromophenylphenylether	mg/kg	32	0			
	4-Chloro-3-methylphenol	mg/kg	32	0			
	4-Chloroaniline	mg/kg	32	0			
	4-Chlorophenylphenylether	mg/kg	32	0			
	4-Methylphenol	mg/kg	32	12	0.177	177	38.32
	4-Nitroaniline	mg/kg	32	0			
	4-Nitrophenol	mg/kg	32	0			
	Aniline (TIC)	-	32	0			
	Azobenzene	mg/kg	32	0			
	Biphenyl(TIC)	-	32	0			
	bis(2-Chloroethoxy)methane	mg/kg	32	0			
	bis(2-Chloroethyl)ether	mg/kg	32	0			
	Bis(2-chloroisopropyl)ether	-	32	0			
	bis(2-Ethylhexyl) phthalate	mg/kg	32	22	0.195	384	27.51
	Butylbenzyl phthalate	mg/kg	32	7	0.135	0.56	0.38
	Carbazole	mg/kg	32	1	30.7	30.7	30.70
	Dibenzofuran	mg/kg	32	2	0.146	5.69	2.92
	Diethyl phthalate	mg/kg	32	0			
	Dimethyl phthalate	mg/kg	32	0			
	Hexachlorobenzene	mg/kg	32	0			
	Hexachlorobutadiene	mg/kg	63	0			
	Hexachlorocyclopentadiene	mg/kg	32	0			
	Hexachloroethane	mg/kg	32	0			
	Isophorone	mg/kg	31	0			
	n-Dibutyl phthalate	mg/kg	32	11	0.11	9.61	2.70
	n-Dioctyl phthalate	mg/kg	32	0			
	Nitrobenzene	mg/kg	31	0			
	n-Nitroso-n-dipropylamine	mg/kg	31	0			
	Pentachlorophenol	mg/kg	31	0			
	Phenol	mg/kg	31	8	1.08	62.9	20.90
	TIC report	-	31	22	1	1	1.00
Suite B - Subcontracted: Organics	Aminomethylphosphonic acid	mg/kg	23	17	0.01	86.3	5.42
	Glyphosate	mg/kg	22	16	0.011	0.85	0.19
	Triclosan	mg/kg	22	1	0.6	0.6	0.60
Suite B - TICS	Anthraquinone (TIC)_	-	8	8			
	Benzeneacetic acid	mg/kg	1	1	56.6	56.6	56.60
	Benzenepropanoic acid	mg/kg	2	2	2.61	228	115.31
	Bisphenol A	mg/kg	5	5	15.1	62.9	39.92
	butanoic acid	mg/kg	2	2	1.05	478	239.53
	Butyl tetradecyl ester phthalic acid	mg/kg	3	3	1.77	1.99	1.85
	Cholestanol	mg/kg	1	1	174	174	174.00
	Cholestanol,isomer	mg/kg	1	1	279	279	279.00
	Diisopropylnaphthalene group_	mg/kg	5	5	10.4	81.9	48.84
	Dimethyl Disulphide	mg/kg	1	1	1.62	1.62	1.62
	Diphenyl sulfone	mg/kg	3	3	2.11	2.91	2.45
	Hexadecanoic acid	mg/kg	4	4	2.74	113	48.24
	Hexanoic acid	mg/kg	1	1	233	233	233.00
	Hydroxybenzenepropanoic acid	mg/kg	1	1	110	110	110.00
	Methanethiol	mg/kg	1	1	1.04	1.04	1.04
	Methyl Indole	mg/kg	1	1	1.34	1.34	1.34
	Methylbutanoic acid	mg/kg	2	2	2.33	258	130.17
	Methylethylidenebisphenol	mg/kg	2	2	38.8	66.6	52.70
	Octadecanoic acid	mg/kg	2	2	4.17	59.5	31.84
	Pentanoic acid	mg/kg	2	2	0.53	544	272.27
	Phenanthrenecarboxylic acid	mg/kg	3	3	4.67	6.78	5.84
	Phenanthrenol	mg/kg	1	1	16.3	16.3	16.30
	Phenylmethoxynaphthalene	mg/kg	1	1	9.33	9.33	9.33
	Squalene	mg/kg	1	1	42.2	42.2	42.20
	Tetracosane	mg/kg	1	1	3.97	3.97	3.97
	Tetradecane	mg/kg	4	4	1.22	2.04	1.66
	Tetradecanoic acid	mg/kg	1	1	9.81	9.81	9.81
	Tetramethylbiphenyl	mg/kg	2	2	3.25	3.39	3.32
	Tridecane	mg/kg	3	3	1.23	1.66	1.46
	Unknown 4_	mg/kg	1	1	5.34	5.34	5.34
	Unknown complex matrix	mg/kg	3	3	51.6	178	115.53
	Unknown1	mg/kg	5	5	3.23	139	31.61
	Unknown2	mg/kg	5	5	1.4	14.2	4.66
	Unknown3	mg/kg	4	4	1.35	15	6.30
Suite B - Volatile Organic Compounds	1,1,1,2-Tetrachloroethane	mg/kg	31	0			
	1,1,1-Trichloroethane	mg/kg	31	0			
	1,1,2,2-Tetrachloroethane	mg/kg	31	0			
	1,1,2-Trichloroethane	mg/kg	31	0			
	1,1-Dichloroethane	mg/kg	31	0			
	1,1-Dichloroethene	mg/kg	31	0			
	1,1-Dichloropropene	mg/kg	31	0			
	1,2,3-Trichlorobenzene	mg/kg	31	0			
	1,2,3-Trichloropropane	mg/kg	31	0			
	1,2,4-Trimethylbenzene	mg/kg	31	0			
	1,2-Dibromo-3-chloropropane	mg/kg	31	0			
	1,2-Dibromoethane	mg/kg	31	0			
	1,2-Dichloroethane	mg/kg	31	0			

Table C13: Phase 1 Data - All Stackable Waste - Organic Compounds

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
	1,2-Dichloropropane	mg/kg	31	0			
	1,3,5-Trimethylbenzene	mg/kg	31	0			
	1,3-Dichloropropane	mg/kg	31	0			
	2,2-Dichloropropane	mg/kg	31	0			
	2-Chlorotoluene	mg/kg	31	0			
	4-Chlorotoluene	mg/kg	31	0			
	4-Isopropyltoluene	mg/kg	31	1	4.06	4.06	4.06
	Benzene	mg/kg	31	0			
	Bromobenzene	mg/kg	31	0			
	Bromochloromethane	mg/kg	31	0			
	Bromodichloromethane	mg/kg	31	0			
	Bromoform	mg/kg	31	0			
	Bromomethane	mg/kg	31	0			
	Carbon Disulphide	mg/kg	31	0			
	Carbontetrachloride	mg/kg	31	0			
	Chlorobenzene	mg/kg	31	0			
	Chloroethane	mg/kg	31	0			
	Chloroform	mg/kg	31	1	1.1	1.1	1.10
	Chloromethane	mg/kg	31	0			
	cis-1,2-Dichloroethene	mg/kg	31	0			
	cis-1,3-Dichloropropene	mg/kg	31	0			
	Dibromochloromethane	mg/kg	31	0			
	Dibromomethane	mg/kg	31	0			
	Dichlorodifluoromethane	mg/kg	31	0			
	Dichloromethane	mg/kg	31	0			
	Ethylbenzene	mg/kg	31	0			
	Isopropylbenzene	mg/kg	31	0			
	Methyl Tertiary Butyl Ether	mg/kg	31	0			
	n-Butylbenzene	mg/kg	31	0			
	o-Xylene	mg/kg	31	0			
	p/m-Xylene	mg/kg	31	0			
	Propylbenzene	mg/kg	31	0			
	sec-Butylbenzene	mg/kg	31	0			
	Styrene	mg/kg	31	0			
	Tert-amyl methyl ether	mg/kg	31	0			
	tert-Butylbenzene	mg/kg	31	0			
	Tetrachloroethene	mg/kg	31	0			
	Toluene	mg/kg	31	4	0.149	0.822	0.35
	trans-1,2-Dichloroethene	mg/kg	31	0			
	trans-1,3-Dichloropropene	mg/kg	31	0			
	Trichloroethene	mg/kg	31	1	0.255	0.255	0.26
	Trichlorofluoromethane	mg/kg	31	0			
	Vinyl Chloride	mg/kg	31	0			
	VOC TIC	-	31	4			

Table C14: Phase 1 Data - All Non-Stackable Waste - Organic Compounds

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Other Miscellaneous	C:N Ratio Calculated	-	4	4	4.5	44.4	17.13
	Carbon	mg/L	10	10	18	13500	5739.50
	Diisopropylnaphthalene group	mg/kg	1	1	27.7	27.7	27.70
	Indole	mg/L	1	1	2.51	2.51	2.51
	Octadecenoic Acid, Isomer	mg/L	7	7	5.97	1590	302.44
Suite B - Combined Pesticides / Herbicides	Aldrin	mg/kg	5	0			
		µg/l	31	0			
	alpha-Hexachlorocyclohexane (HCH)	mg/kg	5	0			
		µg/l	31	0			
	Azinphos-methyl	mg/kg	5	0			
		µg/l	31	0			
	beta-Hexachlorocyclohexane (HCH)	mg/kg	5	0			
		µg/l	31	0			
	Diazinon	mg/kg	5	0			
		µg/l	31	0			
	Dichlorvos	mg/kg	5	0			
		µg/l	31	0			
	Dieldrin	mg/kg	5	0			
		µg/l	31	0			
	Disulfoton	mg/kg	5	0			
	Endosulphan I	mg/kg	5	0			
		µg/l	31	0			
	Endosulphan II	mg/kg	5	0			
		µg/l	31	0			
	Endosulphan sulphate	mg/kg	5	0			
		µg/l	31	0			
	Endrin	mg/kg	5	0			
		µg/l	31	0			
	Ethion	mg/kg	5	0			
		µg/l	31	0			
	Fenitrothion	mg/kg	5	0			
		µg/l	31	0			
	gamma-Hexachlorocyclohexane (HCH / Lindane)	mg/kg	5	0			
	Heptachlor	mg/kg	5	0			
		µg/l	31	1	21.1	21.1	21.10
	Heptachlor epoxide	mg/kg	5	0			
		µg/l	31	0			
	Malathion	mg/kg	5	0			
		µg/l	31	0			
	Methyl parathion	mg/kg	5	0			
		µg/l	31	2	9.39	52	30.70
	Mevinphos	mg/kg	5	0			
		µg/l	31	0			
	o,p'-DDD (TDE)	mg/kg	5	0			
		µg/l	31	0			
	o,p-DDE	mg/kg	5	0			
		µg/l	31	0			
	o,p-DDT	mg/kg	5	0			
		µg/l	31	0			
	o,p-Methoxychlor	mg/kg	5	0			
		µg/l	31	0			
	p,p-DDE	mg/kg	5	0			
		µg/l	31	0			
	p,p-DDT	mg/kg	5	0			
		µg/l	31	0			
	p,p-Methoxychlor	mg/kg	5	0			
		µg/l	31	0			
	p,p-TDE (DDD)	mg/kg	5	0			
		µg/l	31	0			
	Parathion	mg/kg	5	0			
		µg/l	31	0			
	Phorate	mg/kg	5	0			
Suite B - Extractable Petroleum Hydrocarbons	EPH Range >C10 - C40	mg/kg	5	5	3240	23800	11584
		µg/l	29	29	997	145000000	5495408
	Interpretation	-	2	2	1	1	1.00
Suite B - Miscellaneous Organics	3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctane-1-sulfor	mg/kg	5	0			
	Branched PFOS	mg/kg	3	0			
		µg/l	14	1	0.106	0.106	0.11
	PFBA (Perfluoro-n-butanoic acid) 357-22-44	mg/kg	5	0			
		ng/l	10	0			
	PFBS (Perfluoro-1-butanesulfonate) 375-73-5	mg/kg	5	0			
		ng/l	15	0			
	PFDA (Perfluoro-n-decanoic acid) 335-76-2	mg/kg	5	0			
		ng/l	14	0			
	PFDoA (Perfluoro-n-dodecanoic acid) 307-55-1	mg/kg	5	0			
		ng/l	14	0			
	PFHpA (Perfluoro-n-heptanoic acid) 375-85-9	mg/kg	5	0			
		ng/l	15	0			

Table C14: Phase 1 Data - All Non-Stackable Waste - Organic Compounds

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
	PFHpS (Perfluoro-1-heptanesulfonate) 375-92-8	mg/kg	5	0			
		ng/l	15	0			
	PFHxA (Perfluoro-n-hexanoic acid) 307-24-4	mg/kg	5	0			
		ng/l	15	0			
	PFHxS (Perfluoro-1-hexanesulfonate) 355-46-4	mg/kg	5	0			
		ng/l	15	0			
	PFNA (Perfluoro-n-nonanoic acid) 375-95-1	mg/kg	5	0			
		ng/l	15	0			
	PFOA (Perfluoro-n-octanoic acid) 335-67-1	mg/kg	5	0			
		ng/l	15	1	91.4	91.4	91.40
	PFOS	mg/kg	3	0			
		mg/L	14	2	0.000127	0.000285	0.00021
	PFOS (Perfluoro-1-octanesulfonate) 1763-23-1	mg/kg	5	0			
		ng/l	15	2	80.3	179	129.65
	PFOSA (Perfluoro-octanesulfonamide) 754-91-6	mg/kg	3	0			
		µg/l	13	0			
	PFPA (Perfluoro-n-pentanoic acid) 2706-90-3	mg/kg	5	0			
		ng/l	15	2	37.5	84.8	61.15
	PFUnA (Perfluoro-n-undecanoic acid) 2508-94-8	mg/kg	5	0			
		ng/l	14	0			
Suite B - Semi-Volatile Organic Compounds	1,2,4-Trichlorobenzene	mg/kg	10	0			
		µg/l	65	0			
	1,2-Dichlorobenzene	mg/kg	10	0			
		µg/l	65	1	6.79	6.79	6.79
	1,3-Dichlorobenzene	mg/kg	10	0			
		µg/l	65	0			
	1,4-Dichlorobenzene	mg/kg	10	0			
		µg/l	65	0			
	2,3,4,6-Tetrachlorophenol (TIC)	-	35	0			
	2,4,5-Trichlorophenol	mg/kg	5	0			
		µg/l	31	0			
	2,4,6-Trichlorophenol	mg/kg	5	0			
		µg/l	31	0			
	2,4-Dichlorophenol	mg/kg	5	0			
		µg/l	31	0			
	2,4-Dimethylphenol	mg/kg	5	0			
		µg/l	31	0			
	2,4-Dinitrotoluene	mg/kg	5	0			
		µg/l	31	0			
	2,6-Dichlorophenol (TIC)	-	35	0			
	2,6-Dinitrotoluene	mg/kg	5	0			
		µg/l	31	0			
	2-Chloronaphthalene	mg/kg	5	0			
		µg/l	31	0			
	2-Chlorophenol	mg/kg	5	0			
		µg/l	31	0			
	2-Methylnaphthalene	mg/kg	5	0			
		µg/l	31	0			
	2-Methylphenol	mg/kg	5	0			
		µg/l	31	3	33.4	238	138.13
	2-Nitroaniline	mg/kg	5	0			
		µg/l	31	0			
	2-Nitrophenol	mg/kg	5	0			
		µg/l	31	0			
	3-Nitroaniline	mg/kg	5	0			
		µg/l	31	0			
	4-Bromophenylphenylether	mg/kg	5	0			
		µg/l	31	0			
	4-Chloro-3-methylphenol	mg/kg	5	0			
		µg/l	31	1	26.2	26.2	26.20
	4-Chloroaniline	mg/kg	5	0			
		µg/l	31	0			
	4-Chlorophenylphenylether	mg/kg	5	0			
		µg/l	31	0			
	4-Methylphenol	mg/kg	5	2	112	183	147.50
		µg/l	31	28	3.32	86700	23132
	4-Nitroaniline	mg/kg	5	0			
		µg/l	31	0			
	4-Nitrophenol	mg/kg	5	0			
		µg/l	31	0			
	Aniline (TIC)	-	35	0			
	Azobenzene	mg/kg	5	0			
		µg/l	31	0			
	Biphenyl(TIC)	-	36	0			
	bis(2-Chloroethoxy)methane	mg/kg	5	0			
		µg/l	31	0			
	bis(2-Chloroethyl)ether	mg/kg	5	0			
		µg/l	31	0			

Table C14: Phase 1 Data - All Non-Stackable Waste - Organic Compounds

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
	Bis(2-chloroisopropyl)ether	-	31	0			
	bis(2-Ethylhexyl) phthalate	mg/kg	5	3	3.76	8.7	5.85
		µg/l	31	10	13.6	5700	802.8
	Butylbenzyl phthalate	mg/kg	5	0			
		µg/l	31	1	314	314	314.0
	Carbazole	mg/kg	5	0			
		µg/l	31	1	45.4	45.4	45.40
	Dibenzofuran	mg/kg	5	0			
		µg/l	31	1	8.09	8.09	8.09
	Diethyl phthalate	mg/kg	5	0			
		µg/l	31	1	31.7	31.7	31.70
	Dimethyl phthalate	mg/kg	5	0			
		µg/l	31	1	22.6	22.6	22.60
	Hexachlorobenzene	mg/kg	5	0			
		µg/l	31	0			
	Hexachlorobutadiene	mg/kg	10	0			
		µg/l	65	0			
	Hexachlorocyclopentadiene	mg/kg	5	0			
		µg/l	31	0			
	Hexachloroethane	mg/kg	5	0			
		µg/l	31	0			
	Isophorone	mg/kg	5	0			
		µg/l	31	2	5.6	8.5	7.05
	n-Dibutyl phthalate	mg/kg	5	0			
		µg/l	31	2	199	486	342.50
	n-Dioctyl phthalate	mg/kg	5	0			
		µg/l	31	0			
	Nitrobenzene	mg/kg	5	0			
		µg/l	31	0			
	n-Nitroso-n-dipropylamine	mg/kg	5	0			
		µg/l	31	0			
	Pentachlorophenol	mg/kg	5	0			
		µg/l	31	0			
	Phenol	mg/kg	5	2	1.17	2.14	1.66
		µg/l	31	20	38.7	5060	1647.25
	TIC report	-	36	36	1	1	1.00
Suite B - Subcontracted: Organics	Aminomethylphosphonic acid	mg/kg	4	3	0.62	19	6.86
		µg/l	29	22	0.085	209	21.94
	Glyphosate	mg/kg	4	1	0.054	0.054	0.05
		µg/l	28	21	0.49	150	17.02
	Triclosan	mg/kg	4	0			
		µg/l	29	6	1.23	25.6	9.00
Suite B - TICS	Benzeneacetic acid	µg/l	11	11	889	103000	30056
	Benzenepropanoic acid	µg/l	9	9	759	95800	25482
	Cholestanol	µg/l	5	5	1670	125000	31082
	Hexadecanoic acid	µg/l	8	8	2450	2050000	624554
	Hexanoic acid	µg/l	6	6	2530	313000	82695
	Methanethiol	µg/l	1	1	233	233	233
	Methyl Indole	mg/kg	1	1	41.5	41.5	41.50
		µg/l	4	4	844	20700	10956
	Octadecanoic acid	µg/l	3	3	388	589000	196979
	Pentanoic acid	µg/l	5	5	1140	27200	14628
	Squalene	mg/kg	1	1	15.2	15.2	15.20
	Tetracosane	µg/l	1	1	357	357	357
	Tetradecanoic acid	µg/l	8	8	337	117000	52808
	Unknown2	mg/kg	1	1	7.52	7.52	7.52
Suite B - Volatile Organic Compounds	1,1,1,2-Tetrachloroethane	mg/kg	5	0			
		µg/l	34	0			
	1,1,1-Trichloroethane	mg/kg	5	0			
		µg/l	34	0			
	1,1,2,2-Tetrachloroethane	mg/kg	5	0			
		µg/l	34	0			
	1,1,2-Trichloroethane	mg/kg	5	0			
		µg/l	34	0			
	1,1-Dichloroethane	mg/kg	5	0			
		µg/l	34	0			
	1,1-Dichloroethene	mg/kg	5	0			
		µg/l	34	0			
	1,1-Dichloropropene	mg/kg	5	0			
		µg/l	34	0			
	1,2,3-Trichlorobenzene	mg/kg	5	0			
		µg/l	34	0			
	1,2,3-Trichloropropane	mg/kg	5	0			
		µg/l	34	0			
	1,2,4-Trimethylbenzene	mg/kg	5	0			
		µg/l	34	1	2.83	2.83	2.83
	1,2-Dibromo-3-chloropropane	mg/kg	5	0			
		µg/l	34	0			

Table C14: Phase 1 Data - All Non-Stackable Waste - Organic Compounds

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
	1,2-Dibromoethane	mg/kg	5	0			
		µg/l	34	0			
	1,2-Dichloroethane	mg/kg	5	0			
		µg/l	34	0			
	1,2-Dichloropropane	mg/kg	5	0			
		µg/l	34	0			
	1,3,5-Trimethylbenzene	mg/kg	5	0			
		µg/l	34	0			
	1,3-Dichloropropane	mg/kg	5	0			
		µg/l	34	0			
	2,2-Dichloropropane	mg/kg	5	0			
		µg/l	34	0			
	2-Chlorotoluene	mg/kg	5	0			
		µg/l	34	0			
	4-Chlorotoluene	mg/kg	5	0			
		µg/l	34	0			
	4-Isopropyltoluene	mg/kg	5	2	23	119	71
		µg/l	34	5	15.9	1710	415.48
	Benzene	mg/kg	5	0			
		µg/l	34	7	1.84	114	26.61
	Bromobenzene	mg/kg	5	0			
		µg/l	34	0			
	Bromochloromethane	mg/kg	5	0			
		µg/l	34	1	1.16	1.16	1.16
	Bromodichloromethane	mg/kg	5	0			
		µg/l	34	3	1.76	1.83	1.80
	Bromoform	mg/kg	5	0			
		µg/l	34	2	7.14	8.29	7.72
	Bromomethane	mg/kg	5	0			
		µg/l	34	0			
	Carbon Disulphide	mg/kg	5	0			
		µg/l	34	8	1.39	45.8	16.70
	Carbontetrachloride	mg/kg	5	0			
		µg/l	34	0			
	Chlorobenzene	mg/kg	5	0			
		µg/l	34	0			
	Chloroethane	mg/kg	5	0			
		µg/l	34	0			
	Chloroform	mg/kg	5	0			
		µg/l	34	2	2.73	3.32	3.03
	Chloromethane	mg/kg	5	0			
		µg/l	29	0			
	cis-1,2-Dichloroethene	mg/kg	5	0			
		µg/l	34	0			
	cis-1,3-Dichloropropene	mg/kg	5	0			
		µg/l	34	0			
	Dibromochloromethane	mg/kg	5	0			
		µg/l	34	3	1.69	6.45	4.51
	Dibromomethane	mg/kg	5	0			
		µg/l	34	0			
	Dichlorodifluoromethane	mg/kg	5	0			
		µg/l	34	0			
	Dichloromethane	mg/kg	5	0			
		µg/l	34	1	24.7	24.7	24.70
	Ethylbenzene	mg/kg	5	0			
		µg/l	34	1	3.01	3.01	3.01
	Isopropylbenzene	mg/kg	5	0			
		µg/l	34	2	32.9	35.3	34.10
	Methyl Tertiary Butyl Ether	mg/kg	5	0			
		µg/l	34	1	3.05	3.05	3.05
	n-Butylbenzene	mg/kg	5	0			
		µg/l	34	0			
	o-Xylene	mg/kg	5	0			
		µg/l	34	1	3.89	3.89	3.89
	p/m-Xylene	mg/kg	5	0			
		µg/l	34	1	9.19	9.19	9.19
	Propylbenzene	mg/kg	5	0			
		µg/l	34	0			
	sec-Butylbenzene	mg/kg	5	0			
		µg/l	34	0			
	Styrene	mg/kg	5	0			
		µg/l	34	0			
	Tert-amyl methyl ether	mg/kg	5	0			
		µg/l	34	0			
	tert-Butylbenzene	mg/kg	5	0			
		µg/l	34	0			
	Tetrachloroethene	mg/kg	5	0			
		µg/l	34	0			

Table C14: Phase 1 Data - All Non-Stackable Waste - Organic Compounds

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
	Toluene	mg/kg	5	2	4.37	10	7.19
		µg/l	34	20	6.72	8550	824.43
	trans-1,2-Dichloroethene	mg/kg	5	0			
		µg/l	34	0			
	trans-1,3-Dichloropropene	mg/kg	5	0			
		µg/l	34	0			
	Trichloroethene	mg/kg	5	0			
		µg/l	34	0			
	Trichlorofluoromethane	mg/kg	5	0			
		µg/l	34	0			
	Vinyl Chloride	mg/kg	5	0			
		µg/l	34	0			
	VOC TIC	-	39	20			
	VOC TICs	µg/l	1	0			

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
	Toluene	mg/kg	5	2	4.37	10	7.19
		µg/l	34	20	6.72	8550	824.43
	trans-1,2-Dichloroethene	mg/kg	5	0			
		µg/l	34	0			

Table C15: Phase 2 Data - Sewage Sludge - Organic Compounds

Treated Sludge

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
Suite B - Combined Pesticides / Herbicides	Aldrin	mg/kg	24	0			
	alpha-Hexachlorocyclohexane (HCH)	mg/kg	24	0			
	Baythroid	mg/kg	24	0			
	beta-Hexachlorocyclohexane (HCH)	mg/kg	24	0			
	Chlordane (cis)	mg/kg	24	0			
	Chlordane (trans)	mg/kg	24	0			
	Chlorothalonil	mg/kg	18	0			
	Cyhalothrin/Karate	mg/kg	24	0			
	Cypermethrins(total)	mg/kg	24	0			
	Deltamethrin	mg/kg	24	0			
	Dieldrin	mg/kg	24	0			
	Disulfoton	mg/kg	24	0			
	Endosulphan I	mg/kg	24	0			
	Endosulphan II	mg/kg	24	0			
	Endosulphan sulphate	mg/kg	24	0			
	Endrin	mg/kg	24	0			
	Fenvalerate	mg/kg	24	0			
	gamma-Hexachlorocyclohexane (HCH / Lindane)	mg/kg	24	0			
	Heptachlor	mg/kg	24	0			
	Heptachlor epoxide	mg/kg	24	0			
	Isodrin	mg/kg	24	0			
	Mirex	mg/kg	24	0			
	o,p'-DDD (TDE)	mg/kg	24	0			
	o,p-DDE	mg/kg	24	0			
	o,p-DDT	mg/kg	24	0			
	o,p-Methoxychlor	mg/kg	24	0			
	p,p-DDE	mg/kg	24	0			
	p,p-DDT	mg/kg	24	0			
	p,p-Methoxychlor	mg/kg	24	0			
	p,p-TDE (DDD)	mg/kg	24	0			
	Pendimethalin	mg/kg	24	0			
	Permethrin	mg/kg	24	0			
	Permethrin I	mg/kg	24	0			
	Permethrin II	mg/kg	24	0			
	Phorate	mg/kg	24	0			
	Tecnazene	mg/kg	24	0			
	Telodrin	mg/kg	24	0			
	Toxaphene	mg/kg	24	0			
	Triadimefon	mg/kg	24	0			
	Triallate	mg/kg	24	0			
	Trifluralin	mg/kg	24	0			
Suite B - Miscellaneous Organics	1,2-Bis(pentabromophenyl) ethane	mg/kg	24	1	0.1	0.1	0.10
	2,2',3,4,4',5'-hexabromodiphenyl ether (BDE-138)	mg/kg	24	0			
	2,2'',3,4,4''-pentabromodiphenyl ether (BDE-85)	mg/kg	24	0			
	2,2',4,4',5,5'-hexabromodiphenyl ether (BDE-153)	mg/kg	24	0			
	2,2',4,4',5,6'-hexabromodiphenyl ether (BDE-154)	mg/kg	24	0			
	2,2'',4,4'',5-pentabromodiphenyl ether (BDE-99)	mg/kg	24	0			
	2,2'',4,4'',6-pentabromodiphenyl ether (BDE-100)	mg/kg	24	0			
	2,2'''',4,4''''-tetrabromodiphenyl ether (BDE-47)	mg/kg	24	0			
	2,3'''',4,4''''-tetrabromodiphenyl ether (BDE-66)	mg/kg	24	0			
	2,4,4''''-tribromodiphenyl ether (BDE-28)	mg/kg	24	0			
	3,3,4,4,5,5,6,6,7,7,8,8,8-tridecafluorooctane-1-sulfonic acid	mg/kg	24	1	0.0307	0.0307	0.03
	Branched PFOS	mg/kg	24	3	0.00287	0.00587	0.004
	Cyclohexane Extractable Matter	mg/kg	24	24	8940	362000	57280.42
	Galoxolide	mg/kg	24	6	1	2.1	1.46
	Hexabromocy clododecane (HBCDD)	mg/kg	24	0			
	Nonylphenol	mg/kg	24	3	0.2	0.46	0.37
	Pentachloronitrobenzene	mg/kg	24	0			
	PFBA (Perfluoro-n-butanoic acid) 357-22-44	mg/kg	24	0			
	PFBS (Perfluoro-1-butanesulfonate) 375-73-5	mg/kg	24	0			
	PFDA (Perfluoro-n-decanoic acid) 335-76-2	mg/kg	24	0			
	PFDoA (Perfluoro-n-dodecanoic acid) 307-55-1	mg/kg	24	0			
	PFHpA (Perfluoro-n-heptanoic acid) 375-85-9	mg/kg	24	0			
	PFHpS (Perfluoro-1-heptanesulfonate) 375-92-8	mg/kg	24	0			
	PFHxA (Perfluoro-n-hexanoic acid) 307-24-4	mg/kg	24	0			
	PFHxS (Perfluoro-1-hexanesulfonate) 355-46-4	mg/kg	24	0			
	PFNA (Perfluoro-n-nonanoic acid) 375-95-1	mg/kg	24	0			
	PFOA (Perfluoro-n-octanoic acid) 335-67-1	mg/kg	24	0			
	PFOS	mg/kg	24	18	0.00304	0.0459	0.01
	PFOS (Perfluoro-1-octanesulfonate) 1763-23-1	mg/kg	24	17	0.00226	0.04	0.01
	PFOSA (Perfluoro-octanesulfonamide) 754-91-6	mg/kg	24	0			
	PFPA (Perfluoro-n-pentanoic acid) 2706-90-3	mg/kg	24	0			
	PFUnA (Perfluoro-n-undecanoic acid) 2508-94-8	mg/kg	24	0			
	Tonalide	mg/kg	24	0			
	Trimethoprim	mg/kg	24	0			
	Tris(1-chloro-2-propyl)phosphate	mg/kg	24	1	0.1	0.1	0.10
	Tris(2-chloroethyl) phosphate	mg/kg	24	0			
Suite B - Semi-Volatile Organic Compounds	1,2,4-Trichlorobenzene	mg/kg	47	0			
	1,2-Dichlorobenzene	mg/kg	47	0			
	1,3-Dichlorobenzene	mg/kg	47	0			
	1,4-Dichlorobenzene	mg/kg	47	0			
	2,4,5-Trichlorophenol	mg/kg	24	0			
	2,4,6-Trichlorophenol	mg/kg	24	0			

Table C15: Phase 2 Data - Sewage Sludge - Organic Compounds

Treated Sludge

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
	2,4-Dichlorophenol	mg/kg	24	0			
	2,4-Dimethylphenol	mg/kg	24	0			
	2,4-Dinitrotoluene	mg/kg	24	0			
	2,6-Dinitrotoluene	mg/kg	24	0			
	2-Chloronaphthalene	mg/kg	24	0			
	2-Chlorophenol	mg/kg	24	0			
	2-Methylnaphthalene	mg/kg	24	0			
	2-Methylphenol	mg/kg	24	0			
	2-Nitroaniline	mg/kg	24	0			
	2-Nitrophenol	mg/kg	24	0			
	3-Nitroaniline	mg/kg	24	0			
	4-Bromophenylphenylether	mg/kg	24	0			
	4-Chloro-3-methylphenol	mg/kg	24	0			
	4-Chloroaniline	mg/kg	24	0			
	4-Chlorophenylphenylether	mg/kg	24	0			
	4-Methylphenol	mg/kg	24	24	25.2	435	154.07
	4-Nitroaniline	mg/kg	24	0			
	4-Nitrophenol	mg/kg	24	0			
	Azobenzene	mg/kg	24	0			
	bis(2-Chloroethoxy)methane	mg/kg	24	0			
	bis(2-Chloroethyl)ether	mg/kg	24	0			
	Bis(2-chloroisopropyl)ether	mg/kg	24	0			
	bis(2-Ethylhexyl) phthalate	mg/kg	24	14	0.964	6.09	2.82
	Butylbenzyl phthalate	mg/kg	24	0			
	Carbazole	mg/kg	24	0			
	Dibenzofuran	mg/kg	24	0			
	Diethyl phthalate	mg/kg	24	0			
	Dimethyl phthalate	mg/kg	24	0			
	Hexachlorobenzene	mg/kg	48	0			
	Hexachlorobutadiene	mg/kg	47	0			
	Hexachlorocyclopentadiene	mg/kg	24	0			
	Hexachloroethane	mg/kg	24	0			
	Isophorone	mg/kg	24	0			
	n-Dibutyl phthalate	mg/kg	24	0			
	n-Dioctyl phthalate	mg/kg	24	0			
	Nitrobenzene	mg/kg	24	0			
	n-Nitroso-n-dipropylamine	mg/kg	24	0			
	Pentachlorophenol	mg/kg	24	0			
	Phenol	mg/kg	24	22	0.867	573	139.92
	TIC report	-	24	24	1	1	1.00
	Total SVOC TIC	mg/kg	24	24	118	1020	406.33
Suite B - Subcontracted: Organics	Aminomethylphosphonic acid	mg/kg	24	24	0.37	5.6	1.66
	Glyphosate	mg/kg	22	22	0.048	0.84	0.27
	Triclosan	mg/kg	24	22	0.2	2.05	0.73
Suite B - Volatile Organic Compounds	1,1,1,2-Tetrachloroethane	mg/kg	23	0			
	1,1,1-Trichloroethane	mg/kg	23	0			
	1,1,2,2-Tetrachloroethane	mg/kg	23	0			
	1,1,2-Trichloroethane	mg/kg	23	0			
	1,1-Dichloroethane	mg/kg	23	0			
	1,1-Dichloroethene	mg/kg	23	0			
	1,1-Dichloropropene	mg/kg	23	0			
	1,2,3-Trichlorobenzene	mg/kg	23	0			
	1,2,3-Trichloropropane	mg/kg	23	0			
	1,2,4-Trimethylbenzene	mg/kg	23	14	0.364	3.45	1.75
	1,2-Dibromo-3-chloropropane	mg/kg	23	0			
	1,2-Dibromoethane	mg/kg	23	0			
	1,2-Dichloroethane	mg/kg	23	0			
	1,2-Dichloropropane	mg/kg	23	0			
	1,3,5-Trimethylbenzene	mg/kg	23	6	0.292	0.93	0.55
	1,3-Dichloropropane	mg/kg	23	0			
	2,2-Dichloropropane	mg/kg	23	0			
	2-Chlorotoluene	mg/kg	23	0			
	4-Chlorotoluene	mg/kg	23	0			
	4-Isopropyltoluene	mg/kg	23	0			
	Benzene	mg/kg	23	0			
	Bromobenzene	mg/kg	23	0			
	Bromochloromethane	mg/kg	23	0			
	Bromodichloromethane	mg/kg	23	0			
	Bromoform	mg/kg	23	0			
	Bromomethane	mg/kg	23	0			
	Carbon Disulphide	mg/kg	23	7	0.239	0.695	0.48
	Carbontetrachloride	mg/kg	23	0			
	Chlorobenzene	mg/kg	23	0			
	Chloroethane	mg/kg	23	0			
	Chloroform	mg/kg	23	0			
	Chloromethane	mg/kg	23	0			
	cis-1,2-Dichloroethene	mg/kg	23	0			
	cis-1,3-Dichloropropene	mg/kg	23	0			
	Dibromochloromethane	mg/kg	23	0			
	Dibromomethane	mg/kg	23	0			
	Dichlorodifluoromethane	mg/kg	23	0			
	Dichloromethane	mg/kg	23	0			
	Ethylbenzene	mg/kg	23	4	0.144	0.178	0.16

Table C15: Phase 2 Data - Sewage Sludge - Organic Compounds

Treated Sludge

Analytical Group	Analyte	Units	No of Samples	No of Detections	Min Detected Concentration	Max Detected Concentration	Average Detected Concentration
	Isopropylbenzene	mg/kg	23	0			
	Methyl Tertiary Butyl Ether	mg/kg	23	0			
	n-Butylbenzene	mg/kg	23	0			
	o-Xylene	mg/kg	23	0			
	p/m-Xylene	mg/kg	23	9	0.337	0.615	0.48
	Propylbenzene	mg/kg	23	1	0.324	0.324	0.32
	sec-Butylbenzene	mg/kg	23	0			
	Styrene	mg/kg	23	0			
	Tert-amyl methyl ether	mg/kg	23	0			
	tert-Butylbenzene	mg/kg	23	0			
	Tetrachloroethene	mg/kg	23	0			
	Toluene	mg/kg	23	22	0.688	11.7	4.94
	trans-1,2-Dichloroethene	mg/kg	23	0			
	trans-1,3-Dichloropropene	mg/kg	23	0			
	Trichloroethene	mg/kg	23	0			
	Trichlorofluoromethane	mg/kg	23	0			
	Vinyl Chloride	mg/kg	23	0			
	VOC TIC	-	23	16			
	VOC TICs	mg/kg	23	23		26.1	7.11

Appendix D - Thresholds for Materials Applied to Land

D.1   Code of Practice For Agriculture Use Of Sewage Sludge (DEFRA).

This guidance defines a number of "potentially toxic elements" (PTEs) and sets limits for their concentration in receiving soils, and on the rate at which these PTEs are added to soils.

Except for applications to grassland no limits have been set for PTE concentrations in sludge used in agriculture. Sludge to be surface applied to grassland should not contain lead or fluoride individually in excess of 1200 and 1000 mg/kg dry solids respectively.

	Maximum permissible concentration of PTE in soil (mg/kg dry solids)								Maximum permissible average annual rate of PTE addition over 10 years (kg/ha)
	Arable				Grassland				All soils
PTE	pH 5-5.5	pH 5.5-6	pH 6.0-7	pH >7	pH 5-5.5	pH 5.5-6	pH 6.0-7	pH >7	
Zinc	200	200	200	300	200	200	200	300	15
Copper	80	100	135	200	130	170	225	330	7.5
Nickel	50	60	75	110	80	100	125	180	3
	pH >5				pH >5				
Cadmium	3				3				0.15
Lead	300				300				15
Mercury	1				1.5				0.1
Chromium	400				600				15
Molybdenum	4				4				0.2
Selenium	3				5				0.15
Arsenic	50				50				0.7
Fluoride	500				500				20

D.2   Publically Available Specifications PAS 100 and PAS110

The PAS110 standards for whole digestate, separated liquor and separated fibre are dependent on the nitrogen content of the material and are set out below.

Total nitrogen	kg/t	< 1	1 to 1.9	2 to 2.9	3 to 3.9	4 to 4.9	5 to 5.9	6 to 6.9	7 to 7.9	8 to 8.9	9 or more
Cadmium	mg/kg	0.12	0.24	0.36	0.48	0.60	0.72	0.84	0.96	1.08	1.2
Chromium	mg/kg	8	16	24	32	40	48	56	64	72	80
Copper	mg/kg	16	32	48	64	80	96	112	128	144	160
Mercury	mg/kg	0.08	0.16	0.24	0.32	0.40	0.48	0.56	0.64	0.72	0.80
Nickel	mg/kg	4	8	12	16	20	24	28	32	36	40
Lead	mg/kg	16	32	48	64	80	96	112	128	144	160

Total nitrogen	kg/t	< 1	1 to 1.9	2 to 2.9	3 to 3.9	4 to 4.9	5 to 5.9	6 to 6.9	7 to 7.9	8 to 8.9	9 or more
Zinc	mg/kg	32	64	96	128	160	192	224	256	288	320
Non-ABP digestate: E. coli	1,000 CFU/g fresh matter										
Non-ABP digestate: Salmonella spp.	Absent in 25 g fresh matter										
ABP digestate: human and animal pathogen indicator species	As specified by the competent authority/ Animal Health vet/Veterinary Service vet in the "approval in principal" or "full approval"										

PAS100 standards apply to compost derived from source segregated biodegradable materials and wastes. The PAS100 standards for compost are set out below.

Analyte	Units	Limit
Escherichia coli	CFU / g fresh mass	1000
Salmonella spp	25 g fresh mass	Absent
Cadmium	mg / kg dry matter	1.5
Chromium	mg / kg dry matter	100
Copper	mg / kg dry matter	200
Lead	mg / kg dry matter	200
Mercury	mg / kg dry matter	1.0
Nickel	mg / kg dry matter	50
Zinc	mg / kg dry matter	400

D.3   Poultry Litter Ash Quality Protocol

The Quality Protocol sets out end of waste criteria for the production and use of poultry litter ash (PLA) from poultry litter, feathers and straw. If these criteria are met, the resulting outputs will normally be regarded as having been fully recovered and to have ceased to be waste. The composition of the PLA product available for sale must not exceed any of the individual values specified.

Elements	Upper limit (mg/kg solid matter)
As	17
Cd	3
Co	11
Cr	31
Cu	596
Hg	0.5
Mn	3,500
Mo	45
Ni	24

Elements	Upper limit (mg/kg solid matter)
Pb	244
Se	11
V	20
Zn	2063
Dioxin WHO-2005 TEQ (mammals) ng/kg (maximum)	20
Dioxin WHO-2005 TEQ (mammals) ng/kg (average for last 10 samples or each shipment)	10

D.4   Environment Agency "Derivation and Use of Soil Screening Values for Assessing Ecological Risks"

This report presents Soil Screening Values (SSVs) which may be used by the Environment Agency to identify and screen out low risk deployments from the need for further site-specific assessment and justification. In most circumstances, if the predicted soil concentrations are at or below the relevant SSV then the chemical pollution risks to soil and wildlife from the proposed use of waste-derived materials will be low and acceptable. However, where the final soil level exceeds the SSV it will be necessary for the applicant to provide further evidence to reassure the Environment Agency that no unacceptable impacts on soils remain across a broad range of potential scenarios.

It is important to note that SSVs alone should not be used to assess the acceptability of a waste-derived material to be used on agricultural land or in site restoration.

Although their calculation does consider the ecological food chain risks to wildlife, they do not take into account risks to livestock or human health, either directly or indirectly through agricultural food chain transfer. SSVs do not consider the risks to soil productivity (the ability to grow commercial crops) or controlled waters, or take into account biological pathogens or adverse changes to either soil chemistry or texture and physical structure.

Contaminant	SSV mg/kg
Cadmium	0.6
Copper	35.1
Nickel	28.2
Zinc	35.6
Antimony	37
Cobalt	4.2
Molybdenum	5.1
Silver	0.3
Vanadium	2
Benzo[a]pyrene	0.15
Bis(2-ethylhexyl) phthalate	13
Hexachlorobenzene	0.002

Contaminant	SSV mg/kg
Pentachlorophenol	0.6
Polychlorinated alkanes (medium chain)	11.9
Triclosan	0.13
Tris(2-chloroethyl)phosphate	1.1
Tris(2-chloro-1-methylethyl) phosphate	1.8

D.5   European Union Joint Research Centre End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate): Technical proposals

The objective of this study was to provide the full background information and a possible technical proposal on end-of-waste criteria for biodegradable waste subject to biological treatment.

The recommended limits for metals and organic pollutants are set out below.

Limited content of heavy metals and organic pollutants*	mg/kg (dry weight)
Cd	1.5
Cr	100
Cu	200
Hg	1
Ni	50
Pb	120
Zn	600
PAH16~	6

* In the final product, just after the composting/digestion phase and prior to any mixing with other materials

~ sum of naphthalene, acenaphthylene, acenaphthene, fluorene, phenanthrene, anthracene, fluoranthene, pyrene, benzo[a]anthracene, chrysene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, indeno[1,2,3- cd]pyrene, dibenzo[a,h]anthracene and benzo[ghi]perylene

This study also presented a summary of limits for a variety of organic contaminants in compost/digestate and similar materials in Europe. These are summarised in the table below.

	Austria (a)	Belgium (Flanders) (b)	Belgium (Walloonia; digestate) (c)	Germany (d)	Denmark (e)	France (compost) (f)	Luxembourg (g)	Slovenia (h)	Switzerland (i)
PAH	6 (sum for 6 congeners **)	Individual limits for 10 congeners	5 (PAH16)		3 (sum for 11 congeners***)	Individual limits for 3 congeners	10* (PAH16)	3	4* (PA H16)
PCB	0.2 (PCB6)	0.8 (PCB7)	0.15 (PCB7)	****	0.08* (PCB7)	0.8 (PCB7; only for sewage sludge compost)	0.1* (PCB6)	0.4 (1st class) 1.0 (2nd class) (PCB6)	
PCDD/F (ngI-TEQ /kgdm)	20 ng/kg		100 ng/kg	****			20* ng/kg		20* ng/kg
PFC (perfluorinated compounds (sum of PFOS and PFOA)	0.1			0.1					
AOX (adsorbable organic halogens)	500		250						
LAS (linear alkylbenzene sulphonates)			1500*		1300				
NPE (nonylphenol and – ethoxylates)			25*		10				
DEHP (di(2-ethylhexyl)phthalates)			50*		50				

a) Düngemittelverordnung (Fertilizer Regulation)

b) VLAREA Regulation

c) AGW du 14/06/2001 favorisant la valorisation de certains déchets (Promoting the use of certain wastes)

d) Düngemittelverordnung (Fertilizer Regulation)

e) Slambekendtgørelsen (Sludge Order)

f) NF U44-051 and NF U44-095

g) Guidance value

h) Official Gazette of the Republic of Slovenia, no. 62/08

i) Guidance value from ChemRRV 814.81

*= guide value;

**=sum of benzo[a]pyrene, benzo[b]fluoranthene, benzo[k]fluoranthene, benzo[ghi]perylene, fluoranthene and indeno[1,2,3-cd]pyrene;

***=sum of acenaphthene, phenanthrene, fluorene, fluoranthene, pyrene, benzo[b]fluoranthene, benzo[j]fluoranthene, benzo[k]fluoranthene, benzo[a]pyrene, benzo[ghi]perylene and indeno[1,2,3-cd]pyrene;

**** Maximum sum of PCDD/F and dl-PCB: 30 ng WHO-TEQ/kg dm, in some cases additional restrictions for PCDD/F only of maximum 5 ng WHO-TEQ/kg dm;

PAH_{16}= sum of US EPA 16 priority listed polycyclic aromatic hydrocarbons

PCB_6= sum of PCBs 28, 52, 101, 138, 153 and 180;

PCB_7= sum of PCBs 28, 52, 101, 118, 138, 153 and 180;

PCDD/F= sum of 17 polychlorinated dibenzo-p-dioxins/furans expressed in International Toxicity Equivalents;

D.6   Summary

The various thresholds are summarised below.

	Sludge COGAP	EA SSV	PAS100	PAS110	EU JRC	PLA QP
	Soil	Soil	Material	Material	Material	Ash
	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg	mg/kg (unless specified)
Cadmium	3	0.6	1.5	0.12 – 1.2~	1.5	3
Chromium	400		100	8.0- 80~	100	31
Copper	80 – 200*	35.1	200	16 – 160~	200	596
Lead	300		200	16 – 160~	120	244
Mercury	1		1	0.08 – 0.8~	1	0.5
Nickel	50 – 110*	28.2	50	4 – 40~	50	24
Zinc	200 – 300*	35.6	400	32 – 320~	600	2063
Antimony		37				
Arsenic	50					17
Cobalt		4.2				11
Molybdenum	4	5.1				45
Selenium	3					11
Silver		0.3				
Vanadium		2				20
Fluoride	500					
PAH16					6	
Benzo[a]pyrene		0.15				
Bis(2-ethylhexyl) phthalate		13				
Hexachlorobenzene		0.002				
Pentachlorophenol		0.6				
Polychlorinated alkanes (medium chain)		11.9				
Triclosan		0.13				
Tris(2-chloroethyl)phosphate		1.1				
Tris(2-chloro-1-methylethyl) phosphate		1.8				
Dioxin WHO-2005 TEQ (mammals) (maximum)						20 ng/kg
Dioxin WHO-2005 TEQ (mammals) (average for last 10 samples or each shipment)						10 ng/kg

*depending on soil pH

~depending on nitrogen content of material applied