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A review of human health and environmental risks associated with the land application of mechanical-biological treatment outputs

Better regulation science programme
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Executive summary

The application of organic materials from non-agricultural sources to land can provide a range of agronomic benefits, including macronutrients such as nitrogen and phosphorus. However, these benefits must be balanced against the potential risks of any chemical contaminants also present within the applied material.

This report describes a screening assessment of the potential human health and environmental risks from application of mechanical-biological treatment (MBT) outputs to land. Data on the outputs from five MBT plants in England and Wales were collated and assessed. Samples from the plants were analysed for physical, chemical and biological determinands prioritised by the Environment Agency on the basis of potential risks and previous published assessments.

Data from each plant were used to estimate exposure concentrations for each chemical for scenarios related to the land application of MBT outputs. These scenarios were considered to be reasonable 'worst cases' for human health, flora and fauna, and groundwater receptors and included the application of outputs undiluted as a soil-forming material and the application of outputs as limited by nitrogen. Long-term loadings from repeat applications were also considered.

Limit values from several sources were used to evaluate the potential human health and environmental risks, including values from Canada and the Netherlands.

A number of potential risks were identified for all samples from all sites for both human health and the environment for some metals and organic micropollutants in the scenario where MBT outputs were undiluted. Potential risks were also identified for zinc (Zn) and chromium (Cr) at most treatment plants for environmental risks and cadmium (Cd) for human health risks when the application rate of MBT output was limited by nitrogen. Priority organic micropollutants identified as potential environmental and human health risks were triclosan, benzo-a-pyrene and several phthalates.

A significant number of uncertainties were identified in this risk screening related to both the exposure and effects data. However, risk assessments are iterative and a number of recommendations are made below to progress the assessment. These recommendations include:

- The collation of more representative MBT output plant data over a longer time period for all but one of the plants.
- The use of localised ambient background soil concentrations for the identified priority contaminants at the sites expected to receive the application.
- Reassessment of the limit values used, especially for some of the organic micropollutants, to ensure that they represent the best current scientific understanding.

Implementation of these recommendations would reduce uncertainty in the risk assessment. However, there is also a need to provide a transparent and evidence-based path to compliance, for whatever end use is considered reasonable. Development of such an approach should provide clarity and guidance on the assessment and understanding of potential human health and environmental risks from materials being recycled to land.

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1 Introduction

1.1 Report Structure

The aim of this report is to assess the physical and chemical quality of outputs from mechanical-biological treatment (MBT) plants for mixed municipal waste in England and Wales with respect to human and environmental health and the implications of land application. In order to achieve this aim, we were asked to do the following:

- Through the use of a previously published Environment Agency report and current scientific literature, identify any gaps in knowledge or data on the physical and chemical properties of MBT outputs when used in a risk assessment.
- Undertake further analysis of archived samples and/or undertake a sampling programme of contemporary MBT outputs to fill any data gaps.
- Undertake an assessment of the human health and environmental risks associated with land application of these MBT outputs.
- Review the results of this assessment with respect to a previously produced Environment Agency-commissioned risk assessment (PO30129085) on land recycling of MBT outputs.
- Make recommendations based on the assessment of risks on the suitability of MBT for application to land.

This introductory section discusses the form and characteristics of MBT outputs and explains why the use of these technologies for waste treatment is likely to increase in the UK. The section also considers how risks to humans and the environment from the application of organic materials to land are currently evaluated.

Section 2 outlines the prioritisation and selection of physico-chemical determinands required to assess the risks associated with the land application of MBT outputs. Consideration is given to existing EU and international lists of priority determinands for the risk assessment of composts and waste to land streams.

In Section 3 the sampling of MBT outputs from several plants in England and Wales is described along with additional sources of analytical data considered in this project. .

Section 4 gives the results from the sampling undertaken in this project and additional data supplied under confidentiality agreements from previous studies on MBT plants in England and Wales. Due to the specificity of individual plant inputs and treatment technologies these data should ideally be treated on an individual plant basis. The assessment of potential risks should be undertaken at an individual plant scale. However, due the restrictions in the way the data can be presented, summary tables of the collated data from the five plants are given.

Section 5 covers the assessment of potential human health and environmental risks associated with the application to land of MBT outputs using the collated data. A brief outline of the process undertaken, key exposure pathways and risk scenarios are given. This is followed by an evaluation of potential risks using available guidelines, criteria and limit values associated with reasonable worst-case exposure scenarios (DETR 2000).

Finally, in Section 6, conclusions are drawn about the potential human health and environmental risks associated with land application of MBT outputs. Recommendations

are given along with a suggested compliance regime, to provide a possible way forward for the assessment of risks associated with MBT outputs.

1.2 What are mechanical-biological treatment outputs?

Mechanical-biological is the treatment of mixed waste and municipal solid waste feedstocks. Mechanical-biological treatment (MBT) is a generic term for a process stream including mechanical sorting and separation of waste into different fractions of biodegradable and non-biodegradable waste. The outputs from the treatment generally include recyclables, residues and an organic fraction. This organic fraction may be treated by a number of biological stabilisation processes, depending on the end use, which may include anaerobic digestion and/or composting. It is the quality of this final organic output that is the focus of this report.

The use of MBT systems of waste treatment is relatively novel in the UK compared to other EU countries such as Germany and Austria (Steiner 2005). Yet even in Europe, the popularity of composting municipal solid waste has varied over the last 25 years in response to a number of factors (Partl and Cornander 2006). However, the relatively recent introduction of legislation through the implementation of the Landfill Directive (1999/31/EC) has placed restrictions on the proportion of biodegradable municipal solid waste allowed to go to landfill from 2004/5, resulting in renewed interest in MBT.

The application of MBT composts to land is generally not the preferred route for many EU countries that have MBT facilities. In Germany, Switzerland, Austria and the Scandinavian countries refuse-derived fuel and landfill (as stabilised waste) are the key disposal routes, with very limited amounts of MBT outputs composted and going to land (Steiner 2005). Generally, in Member States where the application of MBT composts to land is accepted they confine disposal routes to rehabilitation/regeneration schemes, although some permit applications to agriculture and horticulture (Herrmann 2003).

Composts derived from wastes which have been collected separately at source from other non-biodegradable waste, such as garden waste, forest residues, wood waste and manures, are viewed in a different regulatory light to organic outputs from MBT plants (BSI 2005, WRAP 2007). This is primarily due to the fact that the MBT outputs are not source-segregated but come from a number of mixed waste streams, prior to treatment. This lack of source segregation is one of a number of key regulatory constraints to the application of MBT outputs to land. However, the most recent draft of the Topsoil Standard (BSI 2007) does not specify the need for input material to manufactured topsoils to be source-separated. A more comprehensive description of the historical regulatory background to biowastes in the EU can be found in Archer *et al*. (2005).

1.3 Physico-chemical and biological characteristics of MBT outputs

Judgments made on the quality of MBT outputs clearly depend upon the intended end use for the output. For recycling to land, four product requirements may be considered key (Partl and Cornander 2006):

- Pasteurisation – to remove or reduce pathogens.
- Maturity – odour control and plant tolerance.

- Physical contamination – such as glass and plastics.
- Chemical contamination – primarily metals and organic micropollutants.

These requirements are not dissimilar to those suggested for product standards for composts or topsoils in the UK (BSI 2005, BSI 2007). A general comparison between selected physico-chemical characteristics of a green waste compost and sewage sludges (from a number of processes) from the UK, and MBT outputs from plants across Europe is shown in Table 1.1. Significant differences between the green waste compost and MBT outputs shown in the Table are the carbon and metal contents. It is a widely held view amongst continental European compost producers that MBT outputs represent a relatively poor quality compost in a highly competitive and quality driven market place (http://www.compostnetwork.info/).

Table 1.1 contains relatively little data on the key requirements listed above for pathogens, maturity, physical contamination and organic micropollutants, as many of these data are not readily available. This is especially true for organic micropollutants, for which analytical methods are often complex and costly. In addition, there is a need to balance a potentially inexhaustible list of organic determinands against the likelihood of establishing their presence (Section 2). The focus of such a source-orientated approach for MBT outputs in Australia suggested that pesticides, herbicides and plasticizers should be the key determinand groups (although this would still give rise to significant determinand numbers) (Partl and Cornander 2006). A recent Environment Agency report (2007a) on MBT output quality listed some typical concentration ranges for polychlorinated biphenyls (PCBs, 0.73-1.68 mg kg^{-1}), dioxins and furans (20-40 ITEQ in ng kg^{-1}) and polycyclic aromatic hydrocarbons (PAHs, 1.5-5.0 mg kg^{-1}). PAH concentrations up to 10 mg kg^{-1} in composts derived from a number of organic source streams was also noted by Kupper *et al*. (2005).

Physical contamination of MBT outputs by glass and plastics has previously been an issue, resulting in fields receiving land-applied outputs being described as ‘glittering’ and ‘sparkling’ (Partl and Cornander 2006). More appropriate refining technologies have the capacity to reduce total man-made sharps, including glass, plastic and metal contents to below 0.5 per cent.

Table 1.1 Mean values of selected physico-chemical parameters of MBT outputs from a number of EU MBT plants (from Environment Agency, 2007a), a typical green waste compost and sewage sludge for the UK.

Parameter	MBT Outputs Hogg *et al*. (2002) (n = 100)	MBT Outputs Amlinger *et al*. (2004) (n = 307)	Green waste compost WRAP 2005*	Sewage sludges[#] (n = 7)
Total N (%)	1.27	-	1.3	
Organic C (%)	23[c]	-	40	46
pH	7.8	-	8.2	9.5
Total Zn	542	870	210	563
Total Cu	162	418	57	437
Total Cd	4.5	3.7	0.75	1.31
Total Ni	60	75	15	35
Total Pb	318	486	111	110
Total Hg	1.6	1.7	0.2	1.59
Total Cr	122	131	-	-

(mg kg^{-1} dry weight basis unless otherwise stated)
[#] Stephen Nortcliff (personal communication)

Like organic micropollutants, the microbiological characteristics of the MBT outputs are not widely or routinely reported in the literature. This is not surprising if one considers the paucity of microbiological data on the more common source-segregated composts (Environment Agency 2007b).

Only rather general statements can be made about MBT output quality, especially for physical and chemical quality, due to the specificity of the input streams and the particular treatment technologies employed at individual plants.

1.4 Evaluation of risks associated with land-applied MBT outputs

The evaluation of risks is only one component of a multi-component process of risk assessment that generally also includes collation of exposure data, description of key uses and markets, and the potential migration pathways to key receptors. The most common way of evaluating potential environmental and human health risks from land-applied material is by comparing measured (or estimated) physico-chemical data with published numerical limit values or standards. These comparisons, along with reasonable worst-case exposure scenarios, can be used to evaluate the likely risks of that material under that scenario (DETR 2000).

In the UK, limit values for physico-chemical parameters have been derived with the intention of preventing harmful effects in soil, vegetation, animals and man, and include those given in the code of practice for agricultural use of sewage sludge (DoE 1986), the topsoil standard (BSI 2007), PAS100 (BSI 2005) and Nitrate Vulnerable Zones (Defra 2002). The values are soil concentrations, loadings or ranges of specific chemicals and parameters below which unacceptable effects are not expected to occur. There are currently few specific limit values for MBT outputs in the EU, although the draft Biowaste Directive did propose limit values for some metals, PCBs and PAHs for stabilised biowaste (EU 2001).

For the assessment of human health risks associated with land application of waste in the UK, the existing code of practice for agricultural use of sewage sludge (DoE 1996) arguably provides some coverage for human health exposure routes. Depending on the ‘use scenario’ of the material, it may also be appropriate to use existing Soil Guideline Values (SGVs) developed for use with the Contaminated Land Exposure Assessment model (CLEA) (Environment Agency 2002) as a screening level assessment.

However, a brief consideration of published limit values to evaluate human health and environmental risks associated with land application of MBT outputs highlights some potential issues including:

- The limited number of chemicals (especially organic micropollutants) and microbiological parameters covered by existing UK limit values for the assessment of human and environmental health.
- The underlying, but unproven, assumption that sewage sludges or source-segregated composts are reliable surrogates for all MBT outputs going to land.
- The limited consideration of effects on additional pathways and receptors, such as secondary effects (detrimental effects on one animal that consumes another, thereby moving up the food chain), which are usually considered for hydrophobic chemicals.

The first point is often addressed in other regulatory regimes (especially Part 2a of the Environmental Protection Act) through the use of more comprehensive lists of limit values from other countries, especially Canada, The Netherlands and Australia. However, if this is done it is imperative that the methodologies and assumptions used in calculating the limit value and its intended management purpose in the country of origin are understood before application to an assessment of land applied material in the UK (RCEP 1998). There is also questionable technical merit in listing limit values for contaminants from different jurisdictions without considering the protection goals and understanding the derivation methods (Ministry of the Environment 2003, Provoost et al. 2006). In the Environment Agency's public consultation on a framework and methods for assessing harm to ecosystems from contaminants in soil (Environment Agency 2003), a hierarchy of suitable sources of information for the selection of limit values for ecological protection was given. This hierarchy considered a number of international regimes and technical criteria to ensure consistency and interpretability of risk assessment.

For human health, the process for deriving soil guideline values is an on-going process for the Environment Agency and Defra, with currently eleven published SGVs and one draft SGV available.

Questions have been raised by regulatory organisations internationally about the appropriateness of relying upon limit values for the assessment of risks associated with MBT outputs which have been derived for significantly different material streams, such as sewage sludges and source-segregated composts (Partl and Cornander 2006). Furthermore, recent evidence from a number of national and international research programmes on the fate and behaviour of contaminants in wastes and soils have shown that some of the current limit values for soils used in the EU may be under-protective (De Brouwere and Smolders 2006, Chaudri *et al*. 2007, Gibbs *et al*. 2007, http://www.csiro.au/science/ps3kw.html).

Additional exposure routes, not explicitly considered in existing UK limit values for assessing risks posed by the recycling of organic waste to land, include those related to secondary poisoning and possibly groundwater protection. The chemicals for which secondary poisoning are relevant include cadmium (Cd), but especially organic micropollutants with relatively long half-lives in soil and bioconcentration factors of more than 2000, such as hexabromocyclododecane and perfluorooctanesulfonic acid (PFOS) (Table 3.3).

In this risk assessment, where possible and appropriate, we follow the methods of risk evaluation proposed by the Environment Agency's previous assessment of biowastes (Environment Agency 2007a). Where we differ from this methodology, the reasoning is clearly stated along with any assumptions made.

2 Determinand prioritisation

2.1 Establishing a priority list of determinands for MBT outputs

In order to assess the human health and environmental risks associated with land application of MBT outputs, it is necessary to characterise fully the physico-chemical and biological characteristics of the outputs from individual plants. With such a potentially diverse source of input material to MBT plants, the provision of an exhaustive list that covers all possible contaminants that *may* be present needs to be balanced against the probability and consequence of their occurrence, and the practicalities and costs of producing such data.

Priority chemical determinands in soils in terms of human and environmental health risks can be identified from published lists such as those of the Environment Agency and other publications (Defra and Environment Agency 2002, Environment Agency 2003, BSI 2005, 2007). However, the relevance of chemicals listed in these sources to current MBT outputs is potentially limited, as these lists cover traditional metal determinands or focus on organic micropollutants from historic industrial or agricultural use. Partl and Cornander (2006) carried out a preliminary screening exercise of organic micropollutants from US, Australian and international priority lists and assessed the chemical-specific relevance to MBT outputs. A similar exercise was undertaken by Kupper *et al*. (2005) who prioritised organic micropollutants for analyses in a monitoring programme of compost-like waste on the basis of sources and the potential to be present in green and domestic wastes (Table 2.1).

Table 2.1 Organic determinands chosen for assessing occurrence, fate and impacts of organic pollutants in composts and digestates (Kupper et al. 2005).

Chemical or groups of chemicals	**Main source/application**
Polycyclic aromatic hydrocarbons (PAHs)	Fuel, combustion, fires, road traffic
Polychlorinated biphenyls (PCBs)	Oil in transformers, hydraulic fluids, lubricants, plastics
Polychlorinated dibenzo-*p*-dioxins and furans	Combustion
Polybrominated diphenyl ethers	Flame retardants – in plastics, textiles, electrical equipment, etc.
Hexabromocyclododecane	Flame retardants – in plastics, textiles, electrical equipment, etc.
Tetrabromobisphenol A	Flame retardants – in plastics, textiles, electrical equipment, etc.
Perfluorinated alkyl substances	Stain and water repellents for surface treatments of textiles, fire fighting foams, lubricants, insecticides, surfactants.
Pesticides	Plant and material protection products

Chemical or groups of chemicals	Main source/application
Chlorinated paraffins	Metal working fluids, paints, coatings, sealants, plasticizers
Phthalates	Plasticizers
Nonylphenol	Metabolites of nonylphenol polyethoxylates used as dispersing and emulsifying agents

The draft Biowaste Directive also contained a list of chemicals with accompanying limit values which may be considered as representing a form of priority list (EU 2001). Table 2.2 gives the parameters and respective limit values for the assessment of stabilised biowaste (MBT outputs). It is made clear in the draft that the stabilised biowaste is not intended for application on land used for arable, livestock or horticultural purposes.

Table 2.2 Proposed limit values for compost and stabilised biowaste (mg kg^{-1}) (EU 2001)

Contaminants	Stabilised biowaste
Zn	1500
Cu	600
Cd	5
Ni	150
Pb	500
Cr	600
Hg	5
PCBs	0.4
PAHs	3**
Impurities (> 2 mm)	<3%
Gravel and stones (> 5 mm)	-

**Normalised to an organic matter content of 30%

2.2 Finalised list of determinands for analysis in MBT outputs

The selection of an appropriate list of determinands to characterise MBT outputs will be informed by several considerations, not least the likely end use. The treatment of agricultural land with organic waste must result in some benefit to agriculture or ecological improvement. Therefore, some 'traditional' determinands, such as macronutrients, pH, organic carbon, metals, etc., as listed in PAS100 (BSI 2005), should routinely be selected.

Tables 2.3 and 2.4 give the final list of determinands selected for analysis in MBT outputs, derived after consultation with Environment Agency Policy and Science leads. The lists cover reasonable and generally well-accepted parameters measured in most composts

(nutrients, major anions, pathogens, metals and so on) and a comprehensive range of organic micropollutants (Partl and Cornander 2006). These micropollutants represent a balance between traditional persistent organic micropollutants for which a significant amount is known about their environmental fate and behaviour, such as PCBs, dioxins and PAHs, and chemicals likely to be present in domestic waste for which environmental data are still limited and understanding of fate and behaviour is relatively uncertain Table 2.4 lists the organic micropollutants and provides a summary of their characteristics and some of the associated potential environmental and human health hazards. Much of this information has been gathered from publicly available EU Risk Assessments on these specific chemicals. Soil predicted no-effect concentrations (PNECs) – effectively limit values – have also been listed where available. No attempt has been made to provide limit values for human health-related effects.

Table 2.3 Physico-chemical and biological determinands chosen for assessing the risks to human and environmental heath from the land application of MBT outputs.

Total nitrogen (N)	Ammonium – N (NH_4-N)	Organic carbon (C) by wet chemistry
Total phosphorus (P), reported as phosphate (P_2O_5)	Nitrate – N (NO_3-N)	Total zinc (Zn)
Total potassium (K), reported as potash (K_2O)	Conductivity	Total copper (Cu)
Total magnesium (Mg), reported as magnesium oxide (MgO)	pH	Total cadmium (Cd)
Total sulphur (S), reported as the oxide (SO_3)	Oil content	Total nickel (Ni)
Total calcium (Ca)	Total neutralising value (as CaO)	Total lead (Pb)
Dry matter	Biological oxygen demand (BOD)	Total chromium (Cr)
Total plastic	*E. coli*	Total mercury (Hg)
Stability as measured by carbon dioxide (CO_2) evolution	*Salmonella* spp.	Total fluoride (F)
Total selenium (Se)	Physical contaminants (glass, plastic, metal)	Total molybdenum (Mo)
Total arsenic (As)		

Table 2.4 Organic micropollutants chosen for assessing the risks to human and environmental heath from the land application of MBT outputs and a brief indication of their characteristics and potential hazards.

Substance or groups of substances (CAS No.)	Characteristics and potential concerns**
Dimethyl-, diethyl-, dibutyl-diisobutyl-, butylbenzyl-, dioctyl-, di(ethylhexyl)-, dinonyl- and didecyl-phthalates (131-11-3, 84-66-2, 84-74-2, 84-69-5, 85-68-7, 117-84-0, 117-81-7, 84-76-4, 68515-49-1)	Range in persistence in soils from one day to more than 95 days. PNECs# range from more than 13 mg kg^{-1} for di(ethylhexyl) to 2 mg kg^{-1} for dibutyl down to 1.39 mg kg^{-1} for butylbenzyl Dibutyl, di(ethylhexyl) and butylbenzyl phthalate may cause harm to unborn children and impair fertility (R61, R62). *
Penta-, octa- and deca-bromodiphenylether (32534-81-9, 32536-52-0, 11163-19-5)	These tend to be persistent and very persistent in soils. PNECs for these substances are; penta- 0.38 mg kg^{-1}, octa- ≥ 20.9 mg kg^{-1} and deca- ≥ 87 mg kg^{-1} There is equivocal evidence to suggest that deca- may accumulate through terrestrial food chains. Similarly penta- is potentially a risk via secondary poisoning and accumulates through the food chain. There are thought to be limited human health risks associated with penta, octa- and deca-, although there are significant uncertainties with the assessments due to data limitations.*
Hexabromocyclododecane (25637-99-4)	HBCDD is a persistent, bioaccumulative and toxic substance. A PNEC for the soil compartment of 5.9 mg kg^{-1} has been derived. However, a secondary poisoning value of 15.3 mg kg^{-1} food has been set for mammals. For humans HBCDD may be a reproductive toxin and repeated dose toxin.*
Tert-docecylmercaptan (25103-58-6)	Provisionally this substance has been described as persistent, bioaccumulative and toxic. A PNEC for soil of 0.51 mg kg^{-1} has been calculated using equilibrium partitioning theory. There may potentially be a secondary poisoning risk for this substance. There is limited acute toxicity to mammals but human health-related effects are certain (Environment Agency 2005).
Perfluorooctane sulfonate (PFOS), PFOS derivatives and substances that degrade to PFOS (1763-23-1)	PFOS is a very persistent, bioaccumulative and toxic substance. PFOS is the perfluorooctane sulfonate anion, and is not a substance as such. PNEC for soil has been derived at 46 µg kg^{-1} based on plant data and the use of equilibrium partition theory (Environment Agency 2004). However, the key environmental concern associated with PFOS is in secondary poisoning for both the terrestrial and especially the aquatic compartments. For the terrestrial compartment a soil concentration that would lead to secondary effects for birds and mammals consuming earthworms would be 0.0106 mg kg^{-1} (based on a PNEC oral of 0.067 mg kg^{-1} wwt in food).
Triclosan (3380-34-5)	Triclosan is toxic, persistent, but not bioaccumulative. A possible PNEC of 0.096 µg kg^{-1} has been derived on very limited data (Danish EPA 2003). Triclosan is thought to have limited human health effects (Environment Agency 2007d).
Tributyl tin (56-35-9)	TBT has a half-life in soils of 15-20 weeks. It is especially toxic to animals and aquatic life. A PNEC for soil of 0.059 µg kg^{-1} has been derived through the use of equilibrium partitioning theory. It is dangerous to humans if exposure is over a long time period (R48) (Environment Agency unpublished report).

Substance or groups of substances (CAS No.)	Characteristics and potential concerns**
Polychlorinated biphenyls (PCBs) 18 congeners	See Annex I
Dioxins	See Annex I
Furans	See Annex I
Pentachlorophenol (87-86-5)	PCP is persist and toxic, but not bioaccumulative. A PNEC of 0.6 mg kg^{-1} had been derived. There is limited evidence that PCP is a mammalian carcinogen (R40) (Environment Agency 2008)
Nonylphenol (84852-15-3, 25154-52-3)	Generally the key exposure to soils and sediments is via the aquatic compartment. Recent EU discussions have suggested that a soil PNEC should be between 1.7-3.2 mg kg^{-1} (Steve Dungey, EA, pers. comm.). A value of 10 mg kg^{-1} food was derived for secondary poisoning. There are a range of human health effects including those on reproduction.*
Polycyclic aromatic hydrocarbons (PAHs) 16 USEPA congeners	PAHs, like B(a)P, are identified as persistent, bioaccumulative and toxic substances. A PNEC for direct toxic effects for B(a)P of 53 µg kg^{-1} has been derived along with a secondary poisoning PNEC of 0.86 µg kg^{-1} (see Annex I).*
Mineral oils	No specific data

#PNEC = predicted no-effect concentration

*These data are from EU risk assessments published under the auspices of the Exiting Substance Regulation (793/93/EEC).See http://ecb.jrc.it/esis/index.php?PGM=ora

** No human health-derived values have been given; where relevant, 'R' phases or risk phrases have been given.

Having established a priority list of determinands, it was essential that representative samples of current MBT outputs be taken on which to base a preliminary assessment of risks to humans and the environment associated with land application.

3 Data collection and collation

3.1 Sampling of MBT outputs

Generally, MBT outputs are stored at or near the respective plants in piles or windrows on concrete pads. There are a number of methods available for sampling of waste in such piles or heaps for the purpose of physico-chemical and biological characterisation (EN 2000, Chambers *et al*. 2001). These methods generally require consideration of the physical consistency and the different sampling situations of the material. The similarity of the MBT outputs with composts in terms of physical condition supported the use of the BS EN (2000) method of sampling.

There is no straightforward answer to the question 'how many samples need to be collected to provide an accurate physico-chemical and biological assessment?' Nevertheless, there are some key steps that should be taken, as outlined by Lambkin *et al*. (2004), to obtain a representative sample. These include:

- Identify the population to be sampled, that is, the material and as far as possible its characteristics.
- Define an adequate number of samples based on the accuracy required, the homogeneity of the feedstock, and the degree of mixing during processing and excavation.
- Determine the sampling pattern and subsampling procedure before sampling, and record this.

A schematic of the process from Lambkin *et al*. (2004) is given below in Figure 3.1. This outlines the steps in collecting material through to providing a suitable sample for analysis.

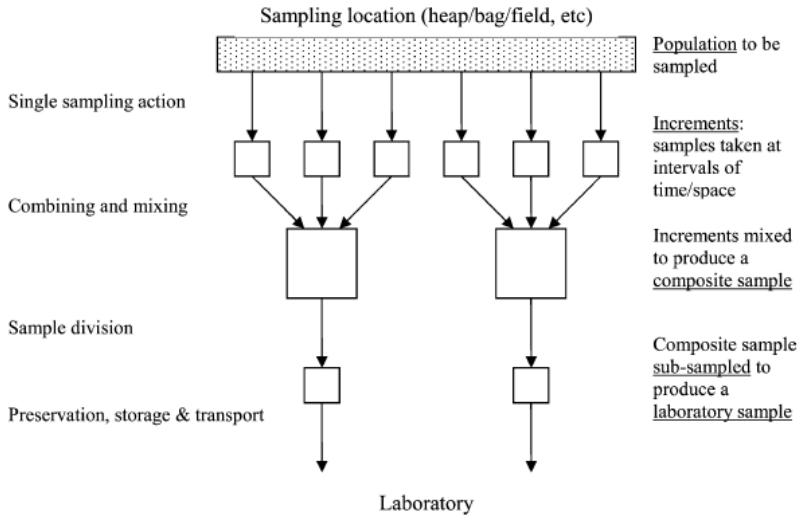

Figure 3.1 A schematic showing the steps in sampling, compositing and subsampling of material (from Lambkin et al. 2004).

A fundamental factor in determining the number of samples to be taken in this sampling programme was analytical costs. The extensive number of determinands listed in Tables 2.3 and 2.4 represented a significant financial commitment and therefore sample numbers

at each plant were greatly restricted (n = 2-4). These samples were unlikely to be entirely representative, spatially or temporally, of the full physico-chemical and biological characteristics of MBT outputs from the specific plants. However, they would provide some indication of the levels of substances which might be expected in UK MBT outputs. The limitations of this sampling programme are considered when drawing conclusions and recommendations in the latter sections of this report.

The Environment Agency initially requested permission to take samples of outputs from five MBT plants in England and Wales. Three plants gave permission and the two others supplied data (Section 3.2). The locations and identities of the plants were anonymised in accordance with requests made by the individual plants. Samples of MBT outputs were taken from the plants from the 25th to the 28th of March 2008. Details of the output stabilisation and storage are given in Table 3.2.

Samples were stored in appropriate vessels (glass jars, polythene bags and so on) before being couriered to three accredited commercial laboratories to undertake the analysis of those determinands cited earlier.

Table 3.2 Stabilisation processes employed at Sites 1-3 from which samples of the MBT outputs were taken.

Site	Outputs storage	Stabilisation Process
Site 1 (n = 3)	Output stored in large metal open top container. Product still very active (warm and steaming).	Sample taken after 8-9 weeks composting. Product is usually left for a further 6-8 weeks maturation before leaving site.
Site 2 (n = 2)	Material direct from conveyor into JCB bucket.	Material un-composted*
Site 3 (n = 4)	Samples taken from pile on pad.	Material sampled after 6-8 weeks composting on a concrete pad.

*This material was intended for landfill only

No samples of any inputs to the MBT plants were taken during the sampling programme.

3.2 Collation of existing data

A number of MBT plants in England and Wales have recently (2005-2007) undertaken a range of physico-chemical and biological analyses on their organic outputs in order to assess suitability for land application. The plants gave permission to the Environment Agency to use these data under the terms of a confidentiality agreement. Three sites provided data, one of which we also sampled. The determinand list selected by these plants was very similar to that chosen in the sampling programme described above.

Initially, it was intended that samples taken for a Department for Environment, Food and Rural Affairs (Defra) project (WRT220) on the characterisation of treated and untreated biodegradable wastes should be re-analysed. This project had sampled a number of MBT outputs and carried out organic compositional tests, metals and leachate analyses (Godley *et al*. 2007). However, in the light of significant changes in treatment processes at some plants, coupled with the need to obtain current information on organic

micropollutants, it was decided that the samples taken in this earlier project would not be re-analysed.

4 Results

4.1 Analytical data from sampling programme

Summary results of the collated analysis of MBT output samples from all three sites are shown in Tables 4.1 and 4.2. In general, the reproducibility of the results from intra sample replicates was acceptable, the only exception being the speciated hydrocarbon contents analysis. For most other determinands the standard deviations obtained for replicate samples suggested that sample homogeneity was fairly consistent (data not shown). A general discussion of these data is given below for a number of the determinand types. Only broad comparisons have been made due to the restrictions place on the use of the data from the outputs.

All three MBT samples showed agriculturally useful levels of macronutrient and carbon contents that would compare favourably (though were slightly lower) than source-segregated composts and sewage sludges (WRAP 2005). The stability of the composts clearly reflects the stabilisation times given in Table 3.2.. Fluoride content was similar for all three sites and nitrate was below the limit of detection (3 mg kg^{-1}) at all of the sites. Mean nitrogen values were similar at all three sites (around 25, 17 and 25 kg t^{-1}).

As might be expected with these fairly dry solids, conductivity was low and the pH ranged from slightly alkaline to slightly acidic. Mean total organic carbon content was 24 per cent for the three sites. Total metal concentrations in the MBT outputs were again relatively consistent across the subsamples from each plant (as reflected in relatively small standard deviations, data not shown) aside from lead (Pb) at one of the sites. Arsenic, selenium (Se) and tributyl tin (TBT) were all below the respective limits of detection (<1 and <4 µg kg^{-1} dry wt^{-1}) in all the samples.

Levels of PAHs did not appear to be particularly high at any of the sites (Environment Agency 2007c). The highest levels for individual PAHs were for fluoranthene and phenanthrene in all samples, as is usually the case for environmental solids.

For the polychlorinated dibenzodioxins and furans (PCDD/F), two of the sites showed low International Toxic Equivalents (ITEQs) with many of the individual (toxic) isomers undetected and the others close to the limit of detection of the analytical method used. The other site showed a significantly higher total ITEQ value but with a few of the individual isomer values at levels still below the limit of detection.

All of the PCB congeners analysed for (PCB 8, PCB 20, PCB 28, PCB 35, PCB 52, PCB 77, PCB 101, PCB 105, PCB 118, PCB 126, PCB 128, PCB 138, PCB 149, PCB 153, PCB 156, PCB 169, PCB 170, PCB 180) were present at levels below the limit of detection (2 µg kg^{-1} dry wt^{-1}) in all of the samples.

Pentachlorophenol was present below the analytical limit of detection of 1 mg kg^{-1} (dry weight) in all of the samples.

For the speciated hydrocarbons the levels reported for one of the three sites were very low, whereas those for the other two were significantly higher and suggested possible low-level contamination with petroleum-derived products. However, the majority of the hydrocarbons present at all of the sites were in the >C21 fractions and risk assessments of several petroleum-derived hydrocarbon products (http://www.concawe.be) have suggested that such fractions do not exhibit persistence, bioaccumulation and toxicity (EC 2003).

PFOS was detected in all of the MBT samples as were a number of the phthalates, with di-n-octylphthalate and diethylhexylphthalate found in all samples.

Triclosan was also detected in all samples of MBT outputs.

There were significant analytical difficulties with the flame retardants, owing to high levels of background contamination in the outputs and so it was not possible to establish spiked sample recovery levels of hexabromocyclododecane, pentabromodiphenyl ethers or octabromodiphenyl ethers despite several attempts.

4.2 Collated analytical data from previous sampling programmes

A summary of the collated analytical data from the MBT outputs from two other plants (and one that was also in the sampling programme) is shown in Table 4.4. Like the samples from the monitoring programme, for most of the determinands standard deviations for replicate samples suggested that sample homogeneity was probably fairly consistent (data not shown).

Only the data for which levels were above analytical limits for all three sites are shown in Table 4.4. Nonylphenol and PAHs were not measured in these previous studies.

Table 4.1 Summary of collated physico-chemical and microbiological data from all three MBT outputs sampled in this project. Means and standard deviations, in brackets, are shown in the shaded columns.

Parameter	Units	Range (n = 9)	Mean(Standard Deviation)
Dry matter	%	62-88	71 (9)
Total N	Kg/t DW	15-26	23 (4)
Readily available N*	mg/kg	<2 -992	410 (509)
Total P	mg/kg	2700-4920	4296 (697)
Total K	mg/kg	4230-9000	6950 (1677)
Total Mg	mg/kg	4760-7340	6060 (1091)
Total SO_3	mg/kg	<10-192	163 (43)
Total Ca	mg/kg	21800-51000	37010 (9700)
Organic C	% DW	20.8-28.8	25 (2.9)
Neutralising value as CaO equivalent	% w/w	1.8-8.5	4.7 (3.0)
pH	pH units	6.12-8.28	6.87 (0.9)
Conductivity	µS/cm	5.8-10	8.8 (1.5)
Compost stability	mgCO_2/g OM/ d	5.0-47.6	23 (15)
Biological oxygen demand (fresh)	mg/l	712-3082	2249 (788)
E. coli	Cfu/g	<10-650000	235000 (308000)
Salmonella spp		Absent	
Total contaminants > 2 mm	%	1.7-14.5	7.0 (4.6)
Glass > 2 mm	%	1.7-14.5	6.6 (4.4)
Metal > 2 mm	%	0-0.56	0.08 (0.19)
Plastic > 2 mm	%	0-1.09	0.31 (0.42)

Table 4.2 Summary of collated values of selected metals and organic contaminants from all three MBT outputs sampled in this project. Means and standard deviations are shown in the shaded columns.

Parameter	Units	Range (n = 9)	Mean(Standard Deviation)
Total arsenic	mg/kg	<1	
Total cadmium	mg/kg	<0.1-2.96	2.0 (0.81)
Total chromium	mg/kg	15-44	24 (9)
Total copper	mg/kg	50-574	387 (192)
Total lead	mg/kg	49-4590	886 (1390)
Total mercury	mg/kg	<2-18	
Total molybdenum	mg/kg	<0.6-0.6	
Total nickel	mg/kg	27-64	55 (13)
Total selenium	mg/kg	<1	
Total zinc	mg/kg	238-1530	865 (410)
Tributyl tin	µg/kg	<3	
Acenaphthene	µg/kg	15-62	40 (18)
Acenaphthylene	µg/kg	7-55	29 (18)
Anthanthrene	µg/kg	<30-98	
Anthracene	µg/kg	35-74	53 (15)
Benzo(a)anthracene	µg/kg	74-160	113 (33)
Benzo(a)pyrene	µg/kg	39-160	81 (37)
Benzo(b)fluoranthene	µg/kg	<200-370	248 (82)
Benzo(e)pyrene	µg/kg	79-200	122 (39)
Benzo(ghi)perylene	µg/kg	51-200	99 (44)
Benzo(k)fluoranthene	µg/kg	<100-120	
Chrysene	µg/kg	100-270	177 (58)
Cyclopenta(cd)pyrene	µg/kg	11-79	32 (20)
Dibenzo(ah)anthracene	µg/kg	9-46	24 (13)
Fluoranthene	µg/kg	160-520	345 (128)
Fluorene	µg/kg	18-70	41 (18)
Indeno(1,2,3cd)pyrene	µg/kg	31-130	63 (31)
Naphthalene	µg/kg	48-180	100 (52)
Perylene	µg/kg	<30-73	
Phenanthrene	µg/kg	170-490	328 (100)

All units on a dry weight basis.

Table 4.2 continued…..

Parameter	Units	Range (n = 9)	Mean(Standard Deviation)
Sum of all PCDD/Fs*	ng/kg	0-36	14 (15)
Pentachlorophenol	µg/kg	<1000	
PCBs	µg/kg	<2	
Hydrocarbons, total extractable C10 - C40	mg/kg	462-4260	1310 (1200)
Hexabrmocyclododecane	mg/kg	AD	
Tert-dodecyl mercaptan	mg/kg	<2	
Nonylphenol	mg/kg	<1	
Decabromodiphenyl ether	mg/kg	<0.5	
Octabromodiphenyl ether	mg/kg	AD	
Pentabromodiphenyl ether	mg/kg	AD	
PFOS (ug/kg)	µg/kg	0.2-3.5	1.6 (1.2)
Butylbenzylphthalate	mg/kg	< 0.1-6.3	4.8 (2.0)
Di-n-nonylphthalate	mg/kg	AD	
Di-n-octylphthalate	mg/kg	0.15-2.2	1.1 (0.77)
Dibutylphthalate	mg/kg	<0.1-7.5	6.3 (0.90)
Diethylhexylphthalate	mg/kg	13-96	64 (35)
Diethylphthalate	mg/kg	<0.1-4	2.6 (1.7)
Diisobutylphthalate	mg/kg	<0.1-10	7.2 (4.4)
Dimethylphthalate	mg/kg	< 0.1-0.69	0.53 (0.22)
Triclosan	mg/kg	1.8-18	10 (6.4)

*Values as ITEQ in ng kg^{-1}
AD = Analytical difficulties

Table 4.3 Summary of selected physico-chemical data from the three MBT outputs provided to the project under confidentiality agreements. Means and standard deviations are shown in the shaded columns. The parameters selected were those that did not record 'less than' values.

Parameter	Units	Range (n < 30)	Mean(Standard Deviation)
pH (solid)	pH units	7.1-8.3	8.0 (0.41)
Total N	Kg/t(fw)	5.8-8.9	-
Total organic carbon (TOC)	%	19-36	25 (6)
Arsenic	mg/kg	3.2-8.6	5.0 (1.5)
Cadmium	mg/kg	1.1-1.7	1.3 (0.2)
Chromium	mg/kg	23-99	44 (18)
Copper	mg/kg	100-481	171 (88)
Lead	mg/kg	451-914	695 (113)
Mercury	mg/kg	0.21-0.83	0.60 (0.19)
Molybdenum	mg/kg	3-9	4.4 (1.5)
Nickel	mg/kg	8-108	37 (22)
Selenium	mg/kg	0.40-1.10	0.74 (0.17)
Zinc	mg/kg	430-767	510 (90)
Sum of PCBs	µg /kg	0-194	42 (59)
Dibutyl phthalate	mg/kg	0.14-12.1	1.90 (3.36)
Diisobutyl phthalate	mg/kg	0.2-21.9	3.69 (5.83)
Butylbenzyl phthalate	mg/kg	0-5.95	0.94 (1.61)
Di-n-octylphthalates	mg/kg	0.14-281	48 (93)
DEHP	mg/kg	15-323	73 (79)
PFOS	µg/kg	5-657	65 (140)
Triclosan	mg/kg	0.001-6.69	1.2 (1.66)
PCDD/F (TEQ)	ng/kg	13-42	27 (9.4)
Total hydrocarbons	mg/kg	600-2700	1350 (582)
Total contaminants > 2 mm	%	0-58	6.1 (14.2)

5 Risk assessment

This project aimed to assess environmental and health effects from the application of MBT outputs to soil. Risk assessment comprises three stages: risk formulation, risk evaluation and characterisation, and risk refinement/management (DETR 2000). The process outlined in the Environment Agency's (2007a) previous assessment of risks associated with MBT outputs to land followed this generic process. In line with routine risk assessment practice, the risk scenarios developed in this section are, where data are limited or uncertain, conservative in nature (BSI 2007). Reasonable worst-case assumptions are made about exposure and effects and acknowledge that this screening-type assessment is an early tier in a multi-tiered risk assessment process. Exposure data were treated in two ways: i) in a similar way to the Environment Agency (2007a) study, using the highest measured concentration in the sample, and ii) in an attempt to follow approaches set out in the EU Technical Guidance Document (EC 2003) which is used to assess risks from new or existing substances.

Risks to human health and the environment from the application to land of MBT outputs were evaluated using a range of published limit values and PNECs. Key assumptions made are outlined below, and possible refinements to the assessments are discussed.

5.1 Key receptors and exposure pathways

Migration pathways shown in Figure 5.1 may lead to a number of exposure routes to a range of receptors. In line with CLEA for human health, the most sensitive receptor is a child exposed through playing (direct handling) and ingestion of soil (Environment Agency 2004). Indeed, direct handling and the consumption of produce grown in MBT outputs are likely to be key exposure routes for human health. Risk of harm to the environment may be through direct effects on soil-dwelling organisms or through indirect effects such as secondary poisoning or ground/surface water contamination.

Depending on the use of the MBT outputs, some of the receptors shown in Figure 5.1 will also behave as pathways to other receptors. If there is no hazard event or potential migration pathway to a key receptor then risks will clearly be low. Risks associated with key compartments and exposure pathways are considered for each use or risk scenario in the next subsection.

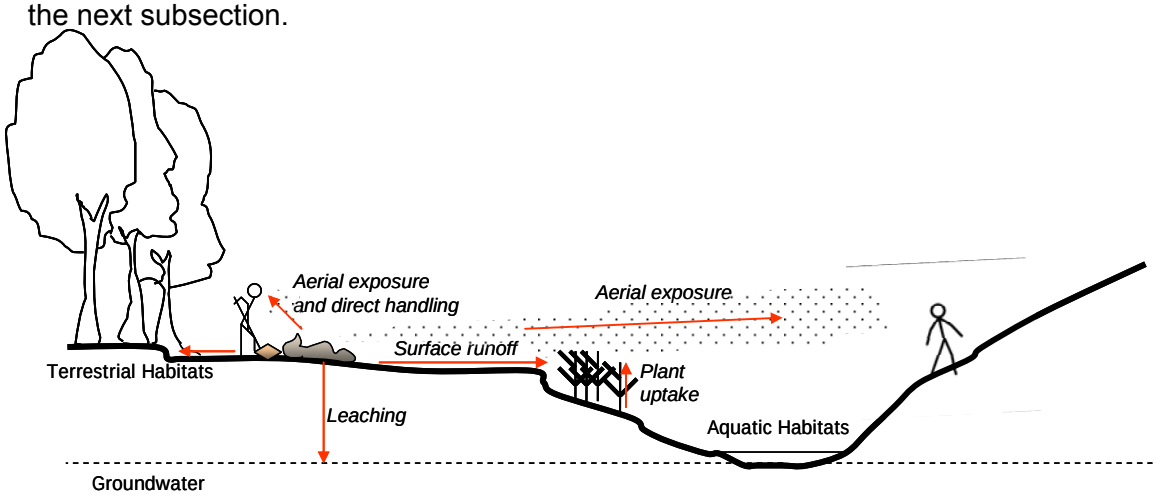

Figure 5.1 Potential migration pathways by which key receptors may become exposed to risks from the land application of MBT outputs.

5.2 Risk formulation

In order to formulate the risks associated with land application of MBT outputs, it was necessary to establish how the physico-chemical data could be used to derive reasonable worst-case exposure contaminant concentrations. Exposure concentrations were derived by two methods, both of which only applied to chemicals for which measurable levels were recorded in all the respective samples and both of which used the data from the individual sites, although only collated summaries are included in the proceeding tables. They two methods were:

- Take the maximum measured concentration recorded from the individual data sets used to produce the summaries in Tables 4.1, 4.2 and 4.3 (Environment Agency 2007a). The use of the collated summary data in Tables 4.1, 4.2 and 4.3 rather than the individual measured data would be not provide a technically appropriate means of assessing potential risks from the application of MBT CLO. The problem with this approach is that only a small number of samples were taken for measurement and we had no way of knowing whether these were representative of concentrations in samples taken at different times. A maximum value might therefore either over- or under-represent true concentrations, perhaps substantially. If the samples were representative of true concentrations in the MBT, a more robust statistical summary would use a high percentile (such as a 90th or 95th percentile), but it was not possible to know with any confidence what distribution should be fitted to the small data samples from which to estimate an appropriate percentile.

- Given sufficient data, calculate a reasonable worst-case concentration by estimating the 90th percentile of the concentration of each chemical from a lognormal distribution (or other appropriate distribution) fitted to the data (using Crystal Ball™ software). Where data were limited (for example, less than four samples) we could assume a distribution similar to that for MBT outputs for which a significant amount of data was available. However, comparison of mean values for sites with limited data with the 10th and 90th percentiles of sites which have significant data (> 24 samples) has shown that such an approach could not be technically justified because mean values for many determinands at these low sample sites were either higher or lower than this range at sites with greater sample numbers (data not shown). This further supports a site/plant-specific approach for the assessment of MBT outputs quality. Without taking more samples, we could not establish whether these differences reflect real differences in the quality of MBT between sites or are simply an artefact of unrepresentative samples.

Having characterised the MBT outputs in terms of selected physico-chemical and biological properties (identified potential hazards) and established the initial exposure concentrations, a number of theoretical generic MBT output ‘uses’ were derived. For this assessment, these uses were associated with the application (or repeat applications and loadings of chemicals) of the MBT outputs to land and included reasonable worst-case assumptions when field data were unavailable. Table 5.1 outlines these uses for this assessment and shows how the exposure concentrations for each of those uses were calculated. Table 5.3 gives examples of the actual calculations used to derive the exposure scenarios from the physico-chemical and biological data.

Two distinct uses of MBT outputs in relation to land application were described. The first was regeneration/remediation/amenity use in which the outputs would be used undiluted as a soil-forming material. The second was for agriculture, where an application would be made in a similar way to sewage sludge. For this last use, two separate calculations were

made, the first in line with work previously commissioned on the assessment of risks of MBT outputs to land, and the second similar to that used in recent EU Risk Assessments for New and Existing Chemicals (EC, 2003). For this second use of MBT outputs, account needs to be taken of existing soil concentrations of chemicals. Like other regulatory regimes involving the application of organic waste to soil (DoE 1986, WRAP 2007), consideration needs to be taken of the levels of chemicals present in the receiving soil prior to application. Therefore, the final exposure calculations for this use scenario were the sum of the concentration of chemical added in the MBT output application and the concentration already present in soil.

Table 5.2 gives the 90th percentile concentrations of selected chemicals, derived from soils data from England and Wales. The 90th percentiles are used to represent reasonable worst-case ambient background concentrations for the characterisation of risks (EC 2003). For a number of the organic micropollutants (such as PFOS, DEHP) data for soils in England and Wales were not available.

Table 5.1 Reasonable worst-case uses associated with land application of MBT outputs and the basis for the calculation of exposure concentrations of contaminants.

Use	Basis for calculation of exposure (rate of application)	Contaminant concentration used	Assumption used in calculation	Calculation
Regeneration, remediation and landscaping	Undiluted MBT outputs	Maximum measured	MBT output is used undiluted for amenity grass	Amount of contaminant in outputs
Regeneration, remediation and landscaping	Undiluted MBT outputs	90th percentile	MBT output is used undiluted for amenity grass	Amount of contaminant in outputs
Applied to agricultural land and ploughed	Limited by nitrogen at 250 kg ha^{-1}*	Maximum measured	1 ha area, depth 0.3 m, bulk density 1.7 g cm^{-3} = 5100 t ha^{-1} of soil	Amount of contaminant in application of output ÷ mass of soil
Applied to agricultural land and ploughed	Limited by nitrogen at 250 kg ha^{-1}*	90th percentile	1 ha area, depth 0.3 m, bulk density 1.7 g cm^{-3} = 5100 t ha^{-1} of soil	Amount of contaminant in application of output ÷ mass of soil
Applied to agricultural land and ploughed	Limited to 5 t ha^{-1} yr^{-1}**	Maximum measured	1 ha area, plough depth 0.2 m (0.1 m), bulk density 1.7 g cm^{-3} = 3400 (1700) t ha^{-1} of soil	Amount of contaminant in application of output ÷ mass of soil
Applied to agricultural land and ploughed	Limited to 5 t ha^{-1} yr^{-1}**	90th percentile	1 ha area, plough depth 0.2 m (0.1 m), bulk density 1.7 g cm^{-3} = 3400 (1700) t ha^{-1} of soil	Amount of contaminant in application of output ÷ mass of soil

*Defra (2002), as used in previous Environment Agency report PO30129085. Mean Total N values were used for each site. Only data from the sampling programme for Site 3 were used, and not the collated data.
**EC (2003) – two depths of incorporation are given: 10 cm for grasslands and 20 cm for arable. To be applied annually over a 10-year period

By combining the reasonable worst-case uses of MBT outputs to land with different exposure scenarios, it is possible to calculate potential exposure concentrations for key

receptors. These exposure scenarios represent the most sensitive exposure situations for the application of MBT outputs to land. For human health, the generally accepted reasonable worst-case scenario is that of a child in a domestic garden accidentally ingesting topsoil (DoE and Environment Agency 2002, US EPA 2002). In addition to direct consumption of soil, there is another human health-related scenario in the consumption of homegrown produce. UK SGVs (Annex I) for residential scenarios are based on the sum of the oral intake, dermal contact and inhalation exposure to a chemical. By implication, other scenarios which do not present these exposure routes can be considered a lower risk for human health (Table 5.4).

Table 5.2 Reasonable worst-case physico-chemical properties from the National Soil Inventory (Zhao et al. 2007) and the Environment Agency (2007c). Units are mg kg^{-1} unless otherwise stated.

Parameter	90th percentile values
Cd	1.4
Cr	64
Cu	37
Ni	42
Pb	131
Zn	147
PCBs (µg kg^{-1})*	0.369
BaP (µg kg^{-1})*	348
PCDD/F (ng kg^{-1} I-TEQ)*	36

*Data for rural soils.

Table 5.3 Examples of the calculation used to derive exposure concentrations for reasonable worst-case uses from Table 5.1 and ambient background concentrations given in Table 5.2.

Use	Basis for calculation of exposure (rate of application)	Contaminant concentration used	Calculation used to derive exposure concentration (PEC)*
Regeneration, remediation and landscaping	Undiluted MBT outputs	Maximum measured in the MBT CLO	For a site, for Zn the concentration used could be 239 mg kg^{-1}.as measured directly in the MBT CLO
Applied to agricultural land and ploughed	Limited by nitrogen at 250 kg ha^{-1}*	Maximum measured	For a site for Cu: There could be 34.7 kg t^{-1} (fw) of N – therefore 250/34.7 gives = 7.2 tonnes (fw) to be applied to 1 ha. The dry weight of the material is 72%, therefore 5.18 t ha^{-1} (dw) will be applied. The maximum Cu concentration in the output could be 574 mg kg^{-1} – 5.18 t of output will contain 4.55 2.97kg of Cu over 1 ha or 5100 t of soil. Therefore, the final Cu concentration from the output applied to 1 ha will be 0.58 mg Cu kg^{-1}. This is then added to the ambient Cu concentration of 37 mg kg^{-1} to give 37.58 mg Cu kg^{-1}.
Applied to agricultural land and ploughed	Limited to 5 t ha^{-1} yr^{-1}**	Maximum measured	For a site for DEHP: Five tonnes of output will be applied to 1 ha. The maximum DEHP concentration in the output could be 96 mg kg^{-1} – 5 t of output will contain 0.48 kg of DEHP to be spread over 1 ha 1700 t - 3400 t of soil#. Therefore, the final DEHP concentration from the output applied to 1 ha will be 0.14 – 0.28 mg DEHP kg^{-1}.

*PEC = Predicted environmental concentration. These calculations assume that the output is uniformly mixed over the entire volume of soil, which may be considered unlikely (De Brouwere and Smolders 2006).
#This depends upon the plough depth chosen – see Table 5.1.

Of the data reviewed in this report, only the unstabilised MBT outputs from one site showed the presence of microbial pathogens (*E. coli*) and as this material is not destined for land application, the risks associated with microbiological pathogens are not considered further.

For environmental risks, the reasonable worst-case scenarios are those related to direct ecotoxicity of the contaminants present to organisms living in or on the natural or manufactured topsoil, including phytotoxicity and adverse effects upon soil-dwelling vertebrates and invertebrates. The key exposure pathways are generally through direct soil ingestion, contact with pore water, or the consumption of contaminated food items (secondary poisoning). Other risk scenarios for the environment include exposure to surface and ground waters from contaminants and nutrients via leaching or runoff. These scenarios (5 and 6) may also be expected to be relevant for situations in which significant volumes of material are stored unbound. The receptors under these final two scenarios could be human health (via drinking and recreational waters) and aquatic flora and fauna and, importantly, may also greatly depend upon the following of good agricultural practice (Defra 2002, 2007), which we have assumed to be the case in Table 5.3.

Table 5.4 Reasonable worst-case exposure scenarios for the application of MBT outputs to land.

Scenario number	Reasonable worst-case scenario	Receptor
1	Child accidentally ingesting soil in a domestic garden or recreational area	Human health
2	Humans consuming produce grown in domestic setting, including allotments and horticulture. In addition to scenario 1	Human health
3	Humans or livestock consuming produce grown in agricultural setting	Human health
4	Organisms living in or on land receiving MBT outputs	Flora and fauna
5	Leaching/runoff of contaminants from a MBT outputs into surface and groundwaters	Human health, aquatic flora and fauna, groundwater, surface water
6	Leaching/runoff of nutrients from a natural or manufactured topsoil into surface and groundwaters	Aquatic flora and fauna, groundwater, surface water

The list of scenarios in Table 5.4 is not exhaustive, but includes those which can be considered as the most sensitive and those considered in other quality protocols for waste to land (WRAP 2007). If through considering these scenarios low risks are identified, then other less sensitive scenarios will clearly also represent low/lower risks to the environment and human health.

5.3 Risk evaluation – environment

In order to evaluate the risks associated with application of MBT outputs to land, a simple characterisation of risk is undertaken. If the ratio of the measured or predicted environmental concentration is equal to or greater than the predicted no-effect concentrations (PEC/PNEC), then there is a risk. Therefore, if a value is above or equal to

one, a potential risk has been identified with that chemical, use and scenario and further investigation is required.

For the general characteristics of MBT outputs, this type of risk characterisation is not necessary in terms of the likelihood and severity of risks. For example, the general characteristics can be used to make a judgement about agricultural or ecological benefit.

5.3.1. General characteristics

The general characteristics of MBT outputs are those shown in Table 4.1 and include physico-chemical parameters to assess the potential agricultural benefit of the outputs. It is likely that additional 'extractable' tests would also be undertaken to assess the full agronomic benefit of applying this material (http://www.defra.gov.uk/farm/environment/land-manage/nutrient/fert/rb209/index.htm).

The quality of the outputs can be gauged through the use of PAS100 (BSI 2005) and more appropriately through BS3882 (BSI 2007). A key consideration under these schemes is the content of visible contaminants and manmade sharps where a target of 0.5 per cent by weight of more than two mm has been set. This was not achieved by any of the wastes considered here, and would have both an aesthetic effect in the short term and a significant adverse effect upon product and risk perception.

All of the outputs contained significant organic carbon contents and had pH values that fitted the general requirements for composts and topsoils. Compost stability (mg CO_2/OM/d) for general purpose source-segregated composts should be below a value of 16. However, none of the three MBT outputs sampled during the course of this project achieved this.

The risks associated with pathogens for all of the stabilised outputs, as mentioned previously, are low.

5.3.2. Metals

Limit values used here for the assessment of metal risks associated with the application of MBT outputs to land were the sludge limit values (DoE 1986) and values from EU risk assessments. Sludge limits are widely used as de facto limits to assess metals risks in soils, and not just those amended with sludge. EU risk assessment limits are more technically developed than the current sludge limits in recognising that the fate, behaviour and subsequent human and ecological impact of metals and organic micropollutants are not solely governed by their total soil concentrations. Factors such as soil pH, clay content and organic carbon may all have a bearing on contaminant behaviour. There are also different routes of contaminant uptake and assimilation for different organisms. Limit values are given in Annex I; in addition to using these values to assess environmental risk, use was also made of a recent output from an Environment Agency project: *Road testing of trigger values for assessing site-specific soil quality*. *Phase 1 – Metals* (SC050054) which incorporates current ecotoxicity data and soil properties to determine the bioavailable metal concentration in soils – the most environmentally relevant metric by which to assess ecological risk.

While EU limits are based on currently available ecotoxicology data and represent the most developed understanding of metal fate and behaviour, the relevance of these values to the application of MBT to land is not known. For our assessment using EU limit values, it was assumed that the outputs were sandy in texture, which represented a reasonable worst case for metals fate and behaviour. This was consistent with using the 10th

percentile values of soil physico-chemical factors, such as pH and organic carbon levels, which have a significant bearing on metal availability (generally availability is reduced as pH and organic carbon levels increase).

Table 5.5 shows a summary of the risk characterisation ratios for the regeneration, remediation and landscaping use of MBT outputs for Scenario 4 for all of the collated MBT CLO analytical data in this project. For metals exposure, Scenarios 5 and 6 represent relatively low risk in the UK if good practice is followed. Metals generally have long residence times in topsoils and leaching is very unlikely to represent a significant migration pathway under reasonable soil management conditions (Han and Thompson 2003). It is clear that for several metals, especially Cu, Pb and Zn, some of the risk characterisation ratios are above one when maximum concentrations or 90th percentiles are used, for both the sludge limits and EU limit values. EU limit values, which consider secondary poisoning, have highlighted potential risks associated with Cd. However, neither the EU limit value or the current sludge limit for Cd consider soil factors (such as pH) which have a significant bearing on the behaviour and fate of Cd (Mclaughlin *et al*. 2006). A greater number of potential risks have been identified using the EU limits for metals and accounting for bioavailability (for Cu, Ni and Zn) when compared with the existing sludge limits.

Of particular interest and some surprise are the risks identified for outputs from all sites for Pb (with one site yielding a risk characterisation ratio of above 27). The source of Pb in the MBT outputs is not clear, although the concentrations across outputs are relatively consistent.

In considering MBT loading rates, it is clear that for the 'undiluted use' of outputs for regeneration and remediation, the rate of application is generally of limited relevance and there are a number of risks associated with the application of MBT outputs undiluted as a soil-forming material. Only under extreme conditions (significant existing contamination) or appropriate management (landfill cover and so on) would the application of MBT outputs for this use be appropriate, with explicit acceptance of the environmental risks to organisms living in or on the land. The use of MBT CLO outputs in regeneration should form part of an agreed, risk-assessed remediation scheme, and in practice should be diluted with other soil-forming materials, or existing site soils.

Table 5.6 shows a summary of the risk characterisation ratios for the use of MBT outputs on agricultural land for application limited by 250 kg ha^{-1} N. The exposure concentrations have been calculated to account for ambient background concentrations in the soils to which the outputs are being applied. Some risks have been identified using the EU limits, especially for Zn, Cd and Cr. Furthermore, for some sites risk characterisation ratios for Pb would exceed one following a further one and six 10 years of repeat MBT output applications.

Table 5.7 shows a summary of the risk characterisation ratios for the use of MBT outputs on agricultural land where application rate is limited to 5 t ha^{-1} yr^{-1} for the incorporation depth of 10 cm (worst-case conditions). As with the N controlled application rate, potential risks have been identified for Cd and Cr using the EU limits in relation to Exposure Scenario 4. The assumption used in the Technical Guidance Document with regard to loadings of material to land is that the applications continue for 10 years. If we assume this to be the case and there is no crop offtake or losses from the topsoil to which the MBT output was applied for these data in Table 5.7, there are only additional risks identified within 10 years for Zn using the EU limits.

Both of the application-based uses calculated here assume uniform mixing, and that the influence and characteristics of the matrix being applied do not persist in the medium to long term in the soil. However, it has recently been shown that for sewage sludges this is

unlikely to be the case and environmental risks may not simply be related to rate of application and total concentration. Indeed, De Brouwere and Smolders (2006) suggested that reductions in wheat yield grown in soils amended with sewage sludges with final soil bulk metal concentrations within EU limits may have been due to the heterogeneous nature of the sludge application. Effectively, this resulted in 'hot spots' of metal levels (and nutrients) where the fate and behaviour would be determined more by the intrinsic properties of the sludge than by the bulk soil.

5.3.3. Organic micropollutants

The limit values used to evaluate environmental risks associated with the organic micropollutants from the application of MBT outputs to land are given in Annex I and Table 2.4. The majority of these limits are from EU risk assessments and the Environment Agency (2008), with some values from other jurisdictions. No suitable limit values were identified for dioctylphthalates or total petroleum hydrocarbons (TPH). Triclosan has not been included in any of the tables below, because the PNEC given in Table 2.4 (0.096 µg kg^{-1}) is very low due to the relative uncertainty in derivation and the consequent use of large assessment factors. On this basis triclosan would represent a potential risk for all uses. For the PAHs, only benzo-a-pyrene (BaP) has been included in the tables, because although Annex I gives PNECs for many PAHs, BaP is relatively data rich and therefore has less associated uncertainty than some of the other PNECs (The Netherlands 2008). However, even for BaP the limit value for secondary poisoning (0.86 µg kg^{-1}) is derived using a number of conservative assumptions in the EU Technical Guidance Document (EC 2003) and is below the fifth percentile of rural England and Wales BaP soil concentrations.

Table 5.8 gives a summary of the risk characterisation ratios for environmental risks (Scenario 4, 5 and 6) for the regeneration/reclamation of all the MBT outputs for organic micropollutants. As with metals, there are a number of risks associated with the use of MBT outputs in this way. In particular, risks are identified for all outputs for dioxins and furans, BaP, DEHP and many of the other phthalates, where measured. Several of these risk characterisation ratios were greater than 10, indicating a high priority for further investigation (EC 2003). Risks of secondary poisoning, shown in parentheses in the table, were also noted for BaP for all plants and PFOS for the outputs from two plants.

A summary of risk characterisation ratios for the nitrogen limited application of MBT outputs to land use for Exposure Scenarios 4, 5 and 6 are shown in Table 5.9. The exposure concentrations calculated for these uses have, where possible, taken account of the ambient background concentrations of organic micropollutants present in the soil. Potential risks have been identified for those organic micropollutants for which backgrounds have been incorporated. The risk characterisation ratios (RCRs) for BaP for secondary poisoning for all sites, where data are available, are a priority for further investigation.

Table 5.10 shows a summary of the risk characterisation ratios for the exposure concentrations for the application of MBT outputs to agricultural land limited to 5 t ha^{-1} for organic micropollutants. As with the data shown in Table 5.9, potential risks have been identified for those chemicals for which exposures have been estimated accounting for ambient background concentrations. No other risks are identified with respect to the 10 years of annual applications of MBT outputs.

Table 5.5 Summary of exposure concentrations and risk characterisation ratios for environmental risks (Scenario 4) for the regeneration/reclamation use of all the MBT outputs (units mg kg^{-1} unless otherwise stated) for metals.

	Range (n=5)					
Parameter		**RCR No units**			**RCR No units**	
	Maximum /Minimum Value	**Sludge limits***	**EU Limits#**	**10th or 90th percentile value$**	**Sludge limits***	**EU limits#**
pH	3.55** - 7.96	-	-	7.46	-	-
SOC(%)	18 - 22.6	-		18	-	-
Cd	1.2 - 2.0	0.4-0.99	1.3-3.29	1.5	0.5	1.67
Cr	20 - 99	005-0.25	0.93 - 4.69	58	0.15	2.75
Cu	88 - 574	0.65-3.33	0.52 - 3.51	181	0.91	1.19
Ni	39 - 108	0.49 – 2.39	0.43	40	0.36	0.36
Pb	425 - 4590	1.41 – 15.3	2.9 – 27.3	839	2.79	5.00
Zn	239 - 1530	1.2 – 7.65	1.5 – 9.75	550	1.83	3.39

*Sludge limits are from DoE (1986).
#EU limits are from EU risk assessments (The Netherlands 2004, ECI 2007, LDAI 2007, Denmark 2007, Belgium 2007) and the Environment Agency (2008).
**This pH value would be too low for a material to be applied to land.
$All lognormal distributions.

Table 5.6 Summary of exposure concentrations and risk characterisation ratios for environmental risks (Scenario 4) for the application to agricultural land (limited by 250 kg ha^{-1} N) use of MBT outputs (units mg kg^{-1} unless otherwise stated) for metals.

	Range (n = 5)					
Parameter		**RCR No units**			**RCR No units**	
	Maximum /Minimum Value	**Sludge limits***	**EU Limits#**	**10th or 90th percentile value$**	**Sludge limits***	**EU limits#**
pH	3.55** - 7.96	-	-	7.46	-	-
SOC(%)	18 - 22.6	-	-	18	-	-
Cd	1.4 – 1.41	0.47	1.56 - 1.58	1.40	0.47	1.56
Cr	64.04 – 64.31	0.16	3.02	64.02	0.16	3.03
Cu	37.21-37.58	0.19 – 0.47	0.210.40	37.06	0.19	0.24
Ni	42.07 – 42.38	0.38 -0.85	0.24 – 0.39	42.13	0.31	0.32
Pb	131.54 – 142.19	0.44 – 0.47	0.78 – 0.85	133.63	0.45	0.80
Zn	147.58 – 148.93	0.33 – 0.75	0.92 – 1.22	148.72	0.50	0.92

*The Sludge limits are from DoE (1986).
#EU Limits are from EU Risk Assessments (The Netherlands 2004, ECI 2007, LDAI 2007, Denmark 2007, Belgium 2007) and the Environment Agency (2008).
**This pH value would be too low for a material to be applied to land.
$All lognormal distributions.

Table 5.7 Summary of exposure concentrations and risk characterisation ratios for environmental risks (Scenario 4) for the application to agricultural land (limited to 5 t ha^{-1}) of all the MBT outputs (units mg kg^{-1} unless otherwise stated) for metals for a 10 cm depth of incorporation.

	Range (n = 5)					
Parameter		**RCR No units**			**RCR No units**	
	Maximum /Minimum values	**Sludge limits***	**EU limits#**	**10th or 90th percentile value$**	**Sludge limits***	**EU limits#**
pH	3.55** - 7.96	-	-	7.46	-	-
SOC(%)	18 - 22.6	-	-	18	-	-
Cd	1.405 – 1.409	0.47	1.56 – 1.57	1.404	0.47	1.56
Cr	64.06 – 64.3	0.16	3.04 – 3.05	64.17	0.16	3.04
Cu	37.26 - 38.69	0.19 – 0.47	0.20 – 0.35	37.53	0.19	0.24
Ni	42.11 - 42.32	0.38 – 0.85	0.28 - 0.94	42.12	0.38	0.39
Pb	132 - 144	0.44 – 0.48	0.44 - 0.79	133.47	0.44	0.79
Zn	147 - 149	0.50 – 0.76	0.92 -1.21	148.61	0.50	0.92

*Sludge limits are from DoE (1986).
#EU limits are from EU risk assessments (The Netherlands 2004, ECI 2007, LDAI 2007, Denmark 2007, Belgium 2007) and the Environment Agency (2008).
**This pH value would be too low for a material to be applied to land.
$All lognormal distributions.

Table 5.8 Summary of exposure concentrations and risk characterisation ratios for environmental risks (Scenario 4, 5 and 6) for the regeneration/reclamation use of all MBT outputs (units mg kg^{-1} unless otherwise stated) for organic micropollutants.

	Range (n = 5)			
Parameter	**Maximum Value**	**RCR No units (2˚ poisoning)**	**90th percentile value***	**RCR No units (2˚ poisoning)**
Sum of all PCDD/Fs*	4.67 - 155	1.17 - 9.05	40.93	10.2
Hydrocarbons - Total extractable	1160 - 4260		1787	
PFOS (µg/kg)	1.1 - 657	(0.01 – 6.20)	19.01	(0.18)
BaP (µg/kg)	67 - 160	1.26 – 3.02 (78 - 186)	-	-
Di-n-octylphthalates	0.24 - 281		206	
Butylbenzylphthalate	1.8 – 5.95	1.29 – 4.53	1.08	0.77
Dibutylphthalate	3 – 12.1	1.5 – 6.05	2.72	1.36
Diisobutylphthalate	5.3 - 22	0.31 – 1.28	5.55	0.32
DEHP	25 - 323	7.08 - 25	219	16.9

^Values as ITEQ in ng kg^{-1}.
*Log normal distributions.

Table 5.9 Summary of exposure concentrations and risk characterisation ratios for environmental risks (Scenario 4, 5 and 6) for the application to agricultural land (limited by 250 kg ha^{-1} N) of all the MBT outputs (units mg kg^{-1} unless otherwise stated) for organic micropollutants.

	Range (n = 5)				
Parameter	**Maximum Value**	**RCR No units (2˚ poisoning)**	**Maximum Value**	**10^{th} or 90^{th} percentile value***	**RCR No units (2˚ poisoning)**
Sum of all PCDD/Fs*	36.0 – 36.5	9.00 - 9.13	36.01	36.13	9.05
Hydrocarbons - Total extractable	4.33 – 9.23		-	5.60	
PFOS (µg/kg)	0.014 – 2.32	(0.0012 - 0.02)	0.023	0.06	0.0006
BaP (µg/kg)	348.07 – 348.20	6.56 -6.57(405 - 406)	348.19	-	-
Di-n-octylphthalates	0.002 – 0.88		0.004	0.65	
Butylbenzylphthalate	0.004 – 0.02	0.004 – 0.036	0.005	0.003	0.002
Dibutylphthalate	0.01 – 0.04	0.007 – 0.020	0.013	0.009	0.005
Diisobutylphthalate	0.007 – 0.08	0.001 – 0.005	0.022	0.017	0.001
DEHP	0.03 – 1.01	0.015 – 0.078	0.19	0.69	0.05

^Values as ITEQ in ng kg^{-1}.
*Log normal distributions.

Table 5.10 Summary of exposure concentrations and risk characterisation ratios for environmental risks (Scenario 4, 5 and 6) for the application to agricultural land (limited to 5 t ha^{-1}) for all MBT outputs (units mg kg^{-1} unless otherwise stated) for metals for a 10 cm depth of incorporation for micropollutants.

	Range (n = 5)			
Parameter	**Maximum Value**	**RCR No units (2˚ poisoning)**	**10th or 90th percentile value***	**RCR No units (2˚ poison)**
Sum of all PCDD/Fs*	36.01 -36.46	9.00 - 9.12	36.12	9.03
Hydrocarbons - Total extractable	3.41 - 12.53		5.26	
PFOS (µg/kg)	0.003 - 1.93	0.00005 - 0.018	0.06	0.0006
BaP (µg/kg)	348.20 – 348.47	6.22 - 6.57(405)	-	-
Di-n-octylphthalates	0.0006 – 0.83		0.61	
Butylbenzylphthalate	0.005 – 0.019	0.004 – 0.014	0.003	0.0021
Dibutylphthalate	0.009 – 0.036	0.009 – 0.018	0.008	0.004
Diisobutylphthalate	0.016 – 0.064	0.0009 – 0.004	0.016	0.0009
DEHP	0.07 – 0.282	0.005 – 0.073	0.64	0.049

^Values as ITEQ in ng kg^{-1}.
*Log normal distribution.

5.4 Risk evaluation – human health

In the UK, few limit values have been derived for human exposure to soil contaminants. Therefore, it was necessary to use values derived by other jurisdictions in order to screen the detected contaminants in the MBT outputs. These values do not reflect all the exposure characteristics used in the CLEA model and software, but are still useful in a screening type of assessment when no other information is available (Annex I). Additional values used, beyond available SGVs, in the evaluation of human health risks are Serious Risk Concentrations (SRCs) derived in The Netherlands (RIVM 2001).

For Exposure Scenarios 1, 2 and possibly 3 (Table 5.11), we used SGVs derived for houses with gardens. The generic exposure scenario in CLEA for the derivation of SGVs uses the child receptor because this receptor is the most sensitive. Although the SGVs were derived for use within Part 2A (contaminated land regime), they can be used in a screening type of assessment such as this one. Several uncertainties exist when using any generically derived values such as SGVs. For example, the mobility of substances in the MBT wastes may differ considerably to those in natural soils, or the types of vegetables used in the derivation of SGVs may not reflect the range of vegetables potentially grown on MBT material.

Despite these uncertainties, given the lack of other values within the UK jurisdiction we believe SGVs are still the most valid. However, there are limited published SGVs and given the number of determinands that needed to be assessed here, we considered it appropriate to use values derived by other European countries such as Holland. RIVM values use different default values for some parameters when deriving SRCs including:

- averaging exposure over a lifetime;
- differences in selection of the tolerable daily intake (TDI);
- potential differences in the number and types of vegetables used.

RIVM values were used for this project despite these differences, as other more suitable values could not be found.

5.4.1 Metals

Table 5.11 lists the exposure concentrations and resulting risk characterisation ratios (RCR) for Scenarios 1, 2 and 3 for the application of MBT outputs as soil-forming material. Lead is identified as a potential risk for all but one site and Ni has RCRs above one for three sites (data not shown). Cadmium has also been shown to be a potential health risk at two sites. When exposure concentrations are estimated using the 90^{th} percentiles generally the RCRs are lower when compared to when maxima are used.

When applications of MBT outputs to land are restricted by N, there are fewer potential human health risks associated with the metals (Table 5.12) compared to the use undiluted. Cadmium is identified as a potential risk at two sites, with RCRs greater than one. Over a period of less than 20 years of annual applications at this same rate, Ni RCRs would exceed one at all but one of the sites. Elevated Cu and Zn concentrations are unlikely to be a human health issue. Table 5.13 shows the exposure concentrations and RCRs associated with applications of MBT outputs limited to 5 t ha^{-1}. As with Table 5.12, potential risks have been identified for Cd for two sites. No further human health risks are identified if we assume 10 years of annual applications of MBT outputs with the same concentrations as those calculated here.

Table 5.11 Summary of exposure concentrations and risk characterisation ratios for human health risks (Scenario 1, 2 and 3) for the regeneration/reclamation use of all the MBT outputs (units mg kg^{-1} unless otherwise stated) for metals.

	Range (n = 5)					
Parameter		RCR No units				
	Maximum /Minimum value	**SGVs***	**Other limits**	**10^{th} or 90^{th} percentile value$**	**SGVs***	**Other limits**
pH	3.55** - 7.96	-	-	7.46	-	-
SOC(%)	18 - 22.6	-	-	18	-	-
Cd	1.2 - 2.0	0.34 - -2.96		1.5	0.30	
Cr	20 - 99	0.16 – 0.76		58	0.45	
Cu	88 - 574		0.01 - 0.06	181	-	0.021
Ni	39 - 108	1.06 – 2.16		40	0.80	
Pb	425 - 4590	0.94 – 10.2		839	1.86	
Zn	239 - 1530	-	0.005 – 0.033	550	-	0.012

*SGVs for residential with private gardens (Annex I).
**This pH value would be too low for a material to be applied to land.
$All lognormal distributions.

Table 5.12 Summary of exposure concentrations and risk characterisation ratios for human health risks (Scenario 1, 2 and 3) for the application to agricultural land (limited by 250 kg ha^{-1} N) of all the MBT outputs (units mg kg^{-1} unless otherwise stated) for metals.

	Range (n = 5)					
Parameter		RCR No units				
	Maximum /Minimum value	**SGVs***	**Other limits**	**10^{th} or 90^{th} percentile value**	**SGVs***	**Other limits**
pH	3.55** - 7.96	-	-	7.46	-	-
SOC(%)	18 - 22.6	-	-	18	-	-
Cd	1.40 – 1.41	0.28 – 1.40		1.405	0.28	
Cr	64.04 – 64.31	0.49 – 0.50		64.18	0.49	
Cu	37.21-37.58	-	0.004	37.57	-	0.004
Ni	42.07 – 42.38	0.84 – 0.85		42.13	0.84	
Pb	131.54 – 142.19	0.29 – 0.32		133.63	0.30	
Zn	147.58 – 148.93	-	0.003	148.72	-	0.003

*SGVs for residential with private gardens (Annex I).
**This pH value would be too low for a material to be applied to land.
$All lognormal distributions.

Table 5.13 Summary of exposure concentrations and risk characterisation ratios for human health risks (Scenario 1, 2 and 3) for the application to agricultural land (limited to 5 t ha^{-1}) of all the MBT outputs (units mg kg^{-1} unless otherwise stated) for metals.

	Range (n = 5)					
Parameter		RCR No units				
	Maximum /Minimum value	**SGVs***	**Other limits**	**10^{th} or 90^{th} percentile value**	**SGVs***	**Other limits**
pH	3.55** - 7.96	-	-	7.46	-	-
SOC(%)	18 - 22.6	-	-	18	-	-
Cd	1.405 – 1.409	0.28 – 1.41		1.405	0.28	
Cr	64.06 – 64.3	0.49		64.18	0.49	
Cu	37.26 - 38.69	-	0.004	37.57	-	0.004
Ni	42.11 - 42.32	0.84 – 0.85		42.13	0.84	
Pb	132 - 144	0.29 – 0.30		133.63	0.30	
Zn	147 - 149	-	0.003	148.72	-	0.003

*SGVs for residential with private gardens (Annex I).
**This pH value would be too low for a material to be applied to land.
$All lognormal distributions.

Table 5.14 Summary of exposure concentrations and risk characterisation ratios for human health risks (Scenario 1, 2 and 3) for the regeneration/reclamation use of all the MBT outputs (mg kg^{-1} unless otherwise stated) for organic micropollutants.

	Range (n = 5)					
Parameter		RCR No units				
	Maximum value	**SGVs***	**Other limits**	**90th %ile value$**	**SGV***	**Other limits**
Sum of all PCDD/Fs*	4.67 - 155		0.02 - 0.43	40.93		0.11
Hydrocarbons - Total extractable	1160 - 4260	-		1787	-	
PFOS (µg/kg)	1.1 - 657	-		19.01	-	
BaP (µg/kg)	67 - 160	84 - 200		-	-	
Di-n-octylphthalates	0.24 - 281	-		206	-	
Butylbenzylphthalate	1.8 – 5.95	-	< 0.0001	1.08		<0.0001
Dibutylphthalate	3 – 12.1	-	< 0.001	2.72		<0.001
Diisobutylphthalate	5.3 - 22	-	0.06 – 0.26	5.55		0.07
DEHP	25 - 323	0.42 -5.38		219		3.65

*SGVs for residential with private gardens (Annex I).
**This pH value would be too low for a material to be applied to land. $All lognormal distributions.

Table 5.15 Summary of exposure concentrations and risk characterisation ratios for human health risks (Scenario 1, 2 and 3) for the application to agricultural land (limited by 250 kg ha^{-1} N) of all the MBT outputs (mg kg^{-1} unless otherwise stated) for organic micropollutants**.**

	Range (n = 5)					
Parameter		RCR No units				
	Maximum value	**SGVs***	**Other limits**	**90th %ile value$**	**SGVs***	**Other limits**
Sum of all PCDD/Fs*	36.0 – 36.5		0.10	36.13		0.10
Hydrocarbons - Total extractable	4.33 – 9.23	-		5.60	-	
PFOS (µg/kg)	0.014 – 2.32	-		0.06	-	
BaP (µg/kg)	348.07 – 348.20	435		-	-	
Di-n-octylphthalates	0.002 – 0.88	-		0.65	-	
Butylbenzylphthalate	0.004 – 0.02		< 0.0001	0.003		<0.0001
Dibutylphthalatedibutylphthalate	0.01 – 0.04		< 0.001	0.009		<0.001
Diisobutylphthalate	0.007 – 0.08		<0.0001 - 0.0002	0.017		0.0002
DEHP	0.03 – 1.01		0.001 – 0.017	0.69		0.0115

*SGVs for residential with private gardens (Annex I).
**This pH value would be too low for a material to be applied to land.
$All lognormal distributions.

Table 5.16 Summary of exposure concentrations and risk characterisation ratios for human health risks (Scenario 1, 2 and 3) for the regeneration/reclamation use of all the MBT outputs (mg kg^{-1} unless otherwise stated) for micropollutants.
Limits from other jurisdictions only used when SGVs not available.

	Range (n =5)					
Parameter		RCR No units				
	Maximum /Minimum value	**SGVs ***	**Other limits**	**90th percentile value$**	**SGVs***	**Other limits**
Sum of all PCDD/Fs*	36.01 -36.46		0.10	36.12		0.10
Hydrocarbons - Total extractable	3.41 - 12.53			5.26	-	
PFOS (µg/kg)	0.003 - 1.93			0.06	-	
BaP (µg/kg)	348.20 – 348.47	435		-	-	
Di-n-octylphthalates	0.0006 – 0.83	-		0.61	-	
Butylbenzylphthalate	0.005 – 0.019	-	< 0.0001	0.003		<0.0001
Dibutylphthalate	0.009 – 0.036	-	< 0.001	0.008		<0.001
Diisobutylphthalate	0.016 – 0.064	-	0.0004 – 0.0008	0.016		0.0002
DEHP	0.07 – 0.282		0.001 - 0.005	0.64		0.011

*SGVs for residential with private gardens (Annex I).
**This pH value would be too low for a material to be applied to land. $All lognormal distributions.

5.4.2 Organic micropollutants

Previous risk assessments on the application of MBT output incorrectly stipulated that the Environment Agency was only concerned with three organic micropollutants with respect to human health: PFOS, DHEP and PCP. It is clear that many of the other organic micropollutants listed in Table 2.4 may also be of a concern for human health as well as for the environment.

Table 5.14 gives the estimated exposure concentrations and risk characterisation ratios for human health risks for MBT output use for regeneration/reclamation. Potential risks are identified for BaP for all sites where it was measured, with relatively high risk characterisation ratios (above 80). Potential risks to human health have also been identified for DEHP for three sites.

Tables 5.15 and 5.16 give the estimated exposure concentrations and RCRs from the tonnage-restricted uses of MBT outputs to agricultural land. Both uses have potential risks for BaP for which ambient background concentrations have been included in the exposure estimate. The large RCRs for all outputs for BaP (above 400) suggest this should be a priority for further investigation. Risks are not identified for any of the chemicals under consideration when applications of 10 to 20 years are considered.

No human health-related limit values for PFOS, total extractable hydrocarbons or di-n-octylphthalates were identified from other key jurisdictions. This represents a significant uncertainty in the human health assessment, especially with regard to PFOS. PFOS has been found in sediments and groundwaters when exposure concentrations have been relatively high, such as when fire fighting foams have been extensively used (Moody *et al*. 2003; http://www.buncefieldinvestigation.gov.uk/index.htm).

5.5 Assumptions and refinements

Due to the limitations in sampling, calculation of exposure concentrations and the hypothetical nature of end uses of MBT outputs, this assessment (and others performed to date) should, at best, be considered as risk screening, that is, an early tier within a risk assessment framework. The lack of understanding of how representative the samples are of MBT outputs (apart from those from one site) is of fundamental importance. Further sampling data are required to improve understanding of the broad risks related to the use of MBT outputs.

The lack of data on ambient background concentrations in soils of some organic micropollutants represents a significant uncertainty in the calculation of exposure concentrations, specifically for triclosan, DEHP and PFOS. It could be argued that the use of 90th percentiles of ambient background concentrations is overly conservative, yet in a screening assessment this is the reasonable worst case. Nevertheless, the overriding effect of these background concentrations on the identified risks suggests a need for further refinement. A localised assessment of soils likely to receive MBT outputs would provide more relevant exposure data and would clearly reduce uncertainty and the need for generic assumptions.

The drawbacks and problems of using maximum chemical concentrations in the MBT outputs to assess potential human health and environmental risks have already been outlined. However, where it was possible to undertake a reasonable comparison, some significant differences were noted, especially when comparing risk characterisation ratios for the regeneration/remediation use.

PNECs taken from the EU risk assessments represent triggers for further investigation and are inherently precautionary when accounting for uncertainty. This may be viewed as the case for the limit values for Cd and Cr which are significantly lower than the existing sludge limits. However, the provenance of these EU values and calculations and the assumptions underlying their derivation are all published and readily available. Further, accounting for metal availability and bioavailability through the use of the EU limit values is a significant positive step providing the most relevant metric by which to judge environmental risks. However, for organic micropollutants no account has been taken of the organic carbon content of the soil and a normalisation step could be performed, as the availability of most non-ionic organic micropollutants is strongly determined by the soil organic matter fraction. This step was not taken in this assessment due to the use of multiple source limit values, so the assessment is very much 'worst case' for the organic micropollutants.

The use of limit values from other jurisdictions, whether for human health or the environment, is a step taken out of necessity rather than desire. However, this does represent an additional uncertainty in the assessment of risks.

The risk characterisation from this assessment should be used to inform decision making and enable resources to be proportionately targeted to risks. Most modern risk assessments are designed to be iterative. When risks are identified at lower tiers, a number of paths can be taken to refine the assessment, often through reduction in uncertainty (collection of more or better data), manage the exposures and mitigate releases. This refinement can generally be undertaken in a step-wise manner, with laboratory and field-based testing as options only when less resource-intensive steps have been taken. This has a two-fold advantage: firstly, it means that published data are fully mined and thus avoids unnecessary tests; secondly, tests that do need to be performed are targeted to the uses, exposure scenarios and chemicals of greatest concern. For our assessment, several relatively straightforward refinements could reduce uncertainties associated with exposure and effects calculations.

Refinement of the exposure concentrations:

- More samples of the outputs for a better understanding of spatial and temporal heterogeneity and the likely 'representativeness' of samples. For example, 12 samples could be taken, one a month over a period of one year, to estimate more reliably the 90th percentile concentration of each chemical assessed.

- Better understanding of how input quality relates to output quality, specifically for Cd, Cr, Pb, Zn, DEHP, triclosan and BaP which have all been identified as representing significant potential risks for several uses and scenarios.

- Local soil concentrations of those chemicals identified as representing a potential human health or environmental risk (especially triclosan, PCDD/Fs, BaP and PFOS).

Refinement of PNECs or limit values:

- Reassess the limit values for Cd and Cr using recent data produced by CSIRO (http://www.csiro.au/science/ps3kw.html) for environmental risks. Discuss ways forward for human health screening with the Environment Agency to confirm priority information sources.

- Reassess limit values for triclosan and BaP (for human health and the environment) through discussions with the Environment Agency's Chemical Assessment Unit, Human Health Team and Industrial Producers.

- Undertake a broader investigation into recent soils-related data on PFOS. As a chemical subject to significant political contention, a number of recent studies will inevitably have produced relevant terrestrial data.

Refinement of the risk characterisation:

- Perform the risk characterisation again, including the refinements outlined above. This will provide a focus for any additional data generation or testing.

6 Conclusions and recommendations

6.1 Conclusions

This report assessed human health and environmental risks associated with the application to land of MBT outputs. A generic risk assessment process was followed to screen for risks using available exposure and effects data. The following conclusions can be drawn from assessment of the limited sampled and collated data on the physico-chemical outputs from five MBT plants in England and Wales:

- Data from all the plants was, for the majority of physico-chemical determinands, relatively uniform (intra-sample variability was low), with relatively low standard deviations between samples. However, for the majority of these sites, only 2-4 grab samples were taken. No conclusions can be drawn on the temporal variability of the MBT outputs. The use of maximum measured concentrations of chemicals is not appropriate for the assessment of risk associated with the application of MBT outputs to land. However, with such limited data (apart from one site), this is what was used here. The results from this assessment should be considered as no more than an initial risk screening exercise.

- Sampled outputs all showed low levels of microbiological risks following composting.

- MBT outputs present potential environmental and human health risks from both metals (Cd, Cr, Cu, Ni, Pb and Zn) and a number of organic micropollutants (DEHP, PFOS, BaP and triclosan) when used undiluted as soil-forming material. The use of MBT CLO outputs in regeneration should form part of an agreed, risk-assessed remediation scheme, and in practice should be diluted with other soil-forming materials or existing site soils.

- If it were applied to agricultural land* at rates limited by nitrogen and accounting for existing concentrations of chemicals in the receiving soil, ecological risks could arise for the metals Cd, Cr, Pb and Zn. These risk are identified for many sites with a single application, and using the EU limit values, for all sites. Potential risks are also identified for Zn for all sites using the current EU limit values if applications were repeated annually for 10 years. Similar patterns of risk were noted when exposure concentrations were calculated using the 5 t ha^{-1} yr^{-1} application. The identification of risks was significantly influenced by the use of generic ambient background metal concentrations.

- If MBT CLO were applied to agricultural land* at rates limited by nitrogen or to 5 t ha^{-1} potential risks could arise for the organic contaminant BaP. Only the exposure calculations for BaP and PCDD/Fs account for ambient background levels in rural soils, as no data were readily available for the other contaminants. The risks identified for BaP represent a high priority for further work.

- A number of refinements to the assessment could reduce uncertainties and limit the use of assumptions in the calculation of exposure concentrations, effects assessment and risk characterisation. These refinements would enable a more targeted approach to be taken to further data generation, if warranted.

This assessment considered the potential risks to human and environmental health from the application of MBT outputs to land. However, it should be stressed that it was not the original intention of the plant owners that many of these outputs would be applied to agricultural land.

* The application of MBT outputs are not currently allowed on agricultural land under the lighter touch approach of exemptions. Our stated position is that compost-like output (CLO) from mechanical biological treatment (MBT) of non-segregated municipal solid waste (MSW) should not be spread on agricultural land that is or is likely to be used for growing food for humans or animals. This straightforward position is one we will continue to adopt until we have evidence that CLO (or grey compost) is of sufficient quality and free from risk to allow spreading on land that may be used to grow food or fodder, or for grazing.

6.2 Recommendations and ways forward

6.2.1. Compliance assessment

To assess whether MBT outputs are suitable for applying to land there is a need to provide a transparent, independent and evidence-based path to compliance, for whatever end use is considered reasonable. A compliance-based approach similar to that used to assess 'annual averages' for water quality may be suitable. This would allow account to be taken of temporal variability in output quality, but would be auditable and transparent with regard to non-compliance. Furthermore, as the potential risks associated with an end use increased, so would the demands of monitoring and assessment leading, for example, to site-specific permitting. Such an approach would also provide clarity and direction for stakeholders.

There is a need for consistency and continuity across regulatory regimes. Many of the organic micropollutants in the determinand list in this project can also be found in sewage sludges, manures and composts from green wastes (Kupper *et al*. 2005, Kinney *et al*. 2008). However, assessment of these organic micropollutants is not routinely required in these matrices to meet the requirements of regulatory regimes or protocols. We recommend an inter-comparison of organic micropollutant concentrations in other organic materials going to soil in the UK, such as sewage sludge, animal manures, green waste composts, anaerobic digestates and so on. This would provide regulators and the regulated community with a view of the assessment and management of risks in context and from the broadest perspective. Furthermore, it would also illustrate consistency of approach by regulators irrespective of source material. Anecdotally, many across the sector appear to be link source segregation to low levels of potential environmental and human health risks, but this view is based on equivocal evidence.

It is imperative that any assessment looks for the toxicologically important compounds that are most likely to be present and that have readily achievable limits of detection. Uncertainties and limitations associated with the determination of low levels of chemicals in potentially complex matrices, such as MBT outputs, need to be acknowledged throughout any assessment and reflected in any conclusions drawn in relation to potential risks.

It is also imperative that transparent limit values for the assessment of risks to humans and the environment from the application of organic wastes to land are used. In this project, values from several jurisdictions and sources were used (through necessity), which inevitably led to a reduction in interpretability. Limits taken from defunct or yet to be

implemented EU directives, for which both the scientific and technical provenance remain opaque is a poor way to judge environmental compliance or industrial performance. We recommend the use of a tiered risk-based approach which delivers compliance through 'weight of evidence'. This would comprise a number of data strands, of which only one would be the use of limit values (as an acknowledgement that for some organic chemicals, data is limited and uncertainty significant).

Product and process quality, consistent long-term analytical evidence and, possibly, use of demonstration programmes to confirm risk assessment predictions may be required to deliver an acceptable level of certainty to regulators and stakeholders.

6.2.2. Priorities and opportunities

To deliver some of the requirements outlined above, there is a need to prioritise issues. It is likely that many of the issues relevant to the assessment of risks from MBT outputs applied to agricultural land will also be priorities for other waste/organic materials. This would likely increase the resources available to deliver rapid evidence-based solutions which could be applied across the sector.

The variability in output quality for some chemicals may mean that the use of 12 monthly samples to estimate 90th percentiles as an approach to estimate exposure concentrations is still not technically appropriate. For such chemicals, a better understanding is needed of how input quality relates to output quality. Undertaking life cycle analysis of a number of the priority chemicals from inputs over the source catchment is likely to provide greater clarity. Furthermore, additional physico-chemical characterisation of the output material, in terms of the relationship of chemical concentrations to physical size fractions or specific particles (such as shreds of plastic and DEHP) may provide an indication of where to target risk mitigation measures.

Contaminant degradation in the MBT output was not considered in this assessment, yet should be investigated, specifically in relation to the composting processes. With information gained from the physico-chemical characterisation of outputs, an understanding of the likely rate and magnitude of contaminant loss may be gained.

Collaboration with manufacturers and commercial downstream users of the chemicals identified as concerns, such as triclosan, would meet the needs of the Environment Agency, MBT output producers and industry groups. Recent evidence from collaborative projects by the Environment Agency with industrial partners for a range of targeted objectives from the Water Framework Directive suggest that this may be a mutually beneficial way of delivering solutions to some of the priorities identified in this risk assessment.

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Annex I

Limits used to evaluate environment risks

	For Environmental Risk (in mg kg^{-1} unless otherwise stated)			
	Soil pH			
	5.0<5.5	5.5<6.0	6.0<7.0	>7.0
Zn*^	200	200	200	300
Cu^	80	100	135	200
Ni^	50	60	75	110
Cd	3	3	3	3
Pb	300	300	300	300
Hg	1	1	1	1
Cr	400	400	400	400
Mo	4	4	4	4
Se	3	3	3	3
As	50	50	50	50
Fl	500	500	500	500

Limits for total metal concentrations in sludge-amended soils (mg kg^{-1} dry weight) Sludge (Use in Agriculture) Regulations (1989) and the Sewage Sludge Code of Practice (1986).

Proposed soil screening values for ecological risk assessment (Environment Agency, 2008)

Substance	**Proposed SSV**	**Basis for derivation**
	(mg kg^{-1})	
Benzo(a)pyrene	0.16#	Assessment factor of 10 on earthworm data.
Cadmium	0.9-2.3	SSD for soil ecotoxicity data and secondary poisoning data◊, plus assessment factor of 1-2 on the HC5.
Chromium	21.1	SSD approach and an assessment factor of 1.
Copper	57.8*	SSD approach and an assessment factor of 1.
Lead	167.9	SSD approach and an assessment factor of 2.
Mercury	0.06	Assessment factor of 10 on springtail data.
Nickel	21.0*	SSD approach and an assessment factor of 2.
Pentachlorobenzene	0.029	Secondary poisoning value based on mammal data, plus an AF of 30.
Pentachlorophenol	0.6#	SSD approach with terrestrial toxicity data and an assessment factor of 1.
Tetrachloroethene	0.01#	Assessment factor of 10 on microbial nitrification data.
Toluene	0.3#	Assessment factor of 50 on earthworm data.
Zinc	116.1*	SSD approach with terrestrial toxicity data and an assessment factor of 2.

*These are SSVs for a soil of pH 6.5, organic matter of 2% and clay content of 10%.
#These are SSVs for soil with 2% organic carbon.
◊Based on renal thresholds of terrestrial mammals.

Soil quality guidelines from other jurisdictions

	For environmental risk (in mg kg^{-1} unless otherwise stated)	
	Agricultural land	**Residential and parkland**
PCBs	0.5	1.3
PCDD/F (ng kg^{-1} I-TEQ)	4	4
Total PAHs	1-100	
	Serious Risk Concentrations (SRCeco)*	
Diisobutylphthalate	17	

Source: http://www.ec.gc.ca/ceqg-rcqe/English/Pdf/GAAG_PCBSoil_e.pdf
http://www.ec.gc.ca/ceqg-rcqe/English/Pdf/GAAG_DioxinFuranSoil_e.pdf
http://www.epa.gov/ecotox/ecossl/pdf/eco-ssl_pah.pdf
*RIVM, 2001.

PNEC for the various PAHs for soil organisms (The Netherlands 2008). The limit value for BaP has been used in this assessment.

Compound	**PNEC soil (mg kg^{-1}_{dw})**
Naphthalene	1.0
Anthracene	0.13
Phenanthrene	1.8
Fluoranthene	1.5
Pyrene	1.0
9H-Fluorene	1.0
Acenaphthylene	0.29
Acenaphthene	0.038
Chrysene	0.55
Benzo(a)anthracene	0.079
Benzo(b)fluoranthene	0.28
Benzo(ghi)perylene	0.17
Benzo(k)fluoranthene	0.27
Benzo(a)pyrene	*0.053*
Dibenzo(a,h)anthracene	0.054
Indeno[123*cd*]pyrene	0.13

Limits used to evaluate human health risks

Soil Guideline Values for Human Health Risk (mg kg^{-1} unless otherwise stated)[#]		
	Residential with private gardens[□]	**Residential with managed open space**[□]
As	20	20
Cd	1-8 (dependent on pH)	30
Cr	130	200
Pb	450	450
Hg	8	15
Se	35	260
Ni	50	75
BaP**	0.8	1.2
Phenols	78-280 (dependent on SOM)	21,900-37,300(dependent on SOM)
Toluene	3-14 (dependent on SOM)	3-15 (dependent on SOM)
Napthalene	7-34 (dependent on SOM)	7-34 (dependent on SOM)
Xylene	6-30 (dependent on SOM)	8-38 (dependent on SOM)
Dutch Serious Risk Concentrations (RIVM, 2001)		
Cu	8,600	
Zn	46,100	
Diisobutylphthalate	83	
Butylbenzylphthalate	294,000	
Dibutylphthalate	22,600	
DEHP	60	
PCDD/F (ng kg^{-1})	360	

[#]These values are based on the sum of the oral intake, dermal contact and inhalation exposure (Environment Agency 2004, 2005).

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