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Road Testing of ‘Trigger Values’ for Assessing Site Specific Soil Quality. Phase 1 – Metals

Science Report – SC050054SR1

SCOTLAND & NORTHERN IRELAND FORUM FOR ENVIRONMENTAL RESEARCH

Scottish Environment Protection Agency

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Steve Killeen

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Executive summary

The Environment Agency has long recognised the need for proportionate, consistent, evidence-based environmental protection across regulatory regimes. This has arguably been achieved for surface waters and air. However, relatively limited direct regulation has previously existed for soils. As a modern regulator, the Environment Agency must ensure that standards for soils are used as part of a risk-based approach, as well as being protective of soils and scientifically robust. We seek to avoid standards that are inconsistent across regimes or industries, or overly protective standards that are a burden on industry and landowners and can cause 'pollutant swapping' or other environmentally detrimental effects. Standards should be simple to use and their basis transparent.

The developing policy context, including the need to develop a national soil monitoring network, led the Environment Agency to undertake a project under the auspices of the UK Soil Indicators Consortium to identify a number of soil quality indicators and related 'prompt values' to be used to assess soil quality against a range of soil related functions. Soil quality in this context can be defined as the capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health habitation. 'Prompt values' were recommended for a set of indicators to be used within a tiered hierarchy. 'Prompt values' can be considered as values or ranges of values above or below which a level of change is understood to be critical in terms of the soil's fitness for a specific use. The 'prompt values' were based on scientific evidence, modelled datasets and, in some cases, expert opinion.

The soil indicators, which were primarily chosen for their role in indicating adverse effects upon the soil function of 'environmental interaction'[1], comprised: extractable phosphorous (Olsen P), soil organic carbon (SOC), pH, bulk density, total nitrogen (N), and aqua regia extractable (total) cadmium (Cd), copper (Cu), nickel (Ni), zinc (Zn) and lead (Pb). This report focussed on the performance of the 'prompt values' for metals.

A number of other standards or 'prompt values' for metals in soil currently exist in the scientific, policy and regulatory environments. For example, sewage sludge applications are not permitted on agricultural land where soil metal concentrations exceed specified values and metal additions must not exceed specific loading rates. Indeed, the sludge limits are widely used across many regulatory regimes as *de facto* environmental limit values, covering a range of protection goals for which they were not originally derived. Very few limit values for metals used across the world for environmental and ecosystem protection have been validated. Validation or 'road testing' in this sense means an assessment in the field in order to establish whether the protection goal for which the limit value was set is achieved. There was a clear need to assess the effectiveness of both the established limit values and the proposed 'prompt values' at fulfilling their soil protection goals.

This project therefore aimed to validate ('road test') existing soil metal limit values and proposed soil 'prompt values' in terms of their effectiveness and practicality on a range of soils falling under different soil-related regulatory regimes. The 'effectiveness' was gauged in terms of whether the limit values were predictive of risk conditions for soils

[1] From the six functions of soil: Support of ecological habitat and biodiversity; Food and fibre production; Environmental interaction; Providing a platform; Providing raw materials; and Protecting cultural heritage (from Blum, 1993)

for which secondary data on soil biological process were also available. This is the first time soil limit values for metals have been validated in this way.

A comprehensive database of more than 500 field soils that had received organic material additions (such as sewage sludge, farm manures, compost, paper crumble) was compiled from a number of experiments, with sites representing different soil types and land uses throughout Britain. Each database entry consisted of a suite of soil data (including texture, pH, organic matter content and metal concentrations) together with one or more biological measurements (such as soil microbial biomass, rhizobia numbers, respiration rate, wheat grain cadmium content, earthworm numbers). The biological measurements were used as an indicator of whether there had been a decrease in soil quality due to metals in the organic materials added. A methodology was developed to allow the performance of the different regimes in protecting soil quality to be compared using the soils database, and to highlight instances where the regimes may be under-, over- or sufficiently protective of soil quality.

One of the key findings of the project was that the existing limit values in the Sludge (Use in Agriculture) Regulations and the Code of Practice for Agricultural Use of Sewage Sludge (that is, the existing UK sludge limits) may not be sufficiently protective of soil quality. These values are used not only in these regimes but also ‘read across’ into other legislation and guidelines related to the spreading of materials onto land.

The results also indicated that the Code of Practice for Agricultural Use of Sludge was under-protective of wheat grain cadmium concentrations. This assessment is supported by recently published work, which showed that the current UK soil total cadmium limit of 3 mg/kg was not sufficiently protective against producing grain above the EU grain cadmium maximum permitted concentration of 0.2 mg/kg (fresh weight), unless the soil pH was >6.8. Soil pH has long been known to be a key factor influencing the availability of many metals in soils, although current UK approaches only consider pH as a factor controlling zinc, copper and nickel bioavailability. Given the weight of research evidence and the findings from this project of reduced numbers of under-protected soils where regimes take soil pH into account, we recommend that future changes to UK legislation should embody a pH-based approach for setting soil cadmium limits.

The implementation of lower limits for zinc, copper and cadmium proposed in the EC Working Document on Sludge would reduce the number of under-protected soils compared with current UK legislation. However, the regime had a high number of over-protected soils, which may indicate that the limits for these metals are set too low for some soils. In general, the EU Risk Assessment/SSV ‘prompt values’ performed well in predicting potential risks, but were also over-protective in some situations.

Overall, the project concluded that there was *a balance to be struck* between environmental protection and regulation and the sustainable recycling of organic material to land. What was clear was that both the science and understanding of metal behaviour in soils has moved on significantly in the last decade and more accurate predictions of metal risks are now possible. Furthermore, it is apparent that the existing limit values for metals in soils, so widely used for the *de facto* assessment of environmental metal risks, may not be wholly protective of soil quality.

It is likely that some soils within a national monitoring scheme may have relatively low metal concentrations, below the ‘prompt values’ specified in all the regimes tested in this project, including the EU Risk Assessment/SSVs that were proposed for this purpose. Nevertheless, increased metal concentrations in such soils could be indicative of a long-term threat to soil quality. Hence, within a national monitoring scheme, it may be more appropriate to look at using ‘prompt values’ in combination with an assessment of changes in soil metal concentrations over time above a specified value. Also, in order to provide an early warning that ‘prompt values’ were being approached, a 75 per cent of the ‘prompt value’ ‘early warning’ limit could be set, depending on at what point metals are to be considered in the monitoring scheme. If metal levels are quantified at an early stage of the scheme (that is, at tier one), limited information will be available for each site and an early warning system is advisable. However, at a higher tier (that is, tier 2 or above), information that triggered further investigation and metal analyses will be available and use of the ‘prompt values’ is advised, in line with the Contaminated Land regime.

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1 Policy Context

The Environment Agency has long recognised the need for proportionate, consistent, evidence-based environmental protection across regulatory regimes. This has arguably been achieved for environmental media that have historically been extensively regulated, such as surface waters and air. However, relatively limited direct regulation has previously existed for soils. The multifunctional role of soil (for example, as a growing medium for food crops, a sink for organic ‘wastes’, a repository of industrial emissions) is one that requires significant skill and understanding to balance.

However, the policy context is currently in a state of change. The EU Thematic Strategy for Soil Protection (European Commission (EC), 2002), Defra’s (Department for Environment, Food and Rural Affairs) “First Soil Action Plan for England 2004-2006” (Defra, 2004) and the Environment Agency’s Soil Strategy (Environment Agency, 2007a) have all highlighted the need for information on the status of and recent changes in soil properties to ensure the long-term protection of soil quality and fertility.

As a modern regulator, we must ensure that standards are used as part of a risk-based approach. In this project, we are therefore assessing whether standards are not only protective of soils, but also scientifically robust. We seek to avoid standards that are inconsistent across regimes or industries. We should also avoid overly protective standards that act as a burden on industry or landowners, and can cause ‘pollutant swapping’ or other environmentally detrimental effects – for example by forcing high quality composts to be sent to landfill rather than recycled to land. Standards should be simple to use and their basis transparent, as set out in the Royal Commission’s 21st Report on Setting Environmental Standards (http://www.rcep.org.uk/standards.htm).

2 Background

2.1 Introduction

The developing policy context, including the need to develop a national soil monitoring network, led the Environment Agency to undertake a project under the auspices of the UK Soil Indicators Consortium to identify a number of soil quality indicators and related 'prompt values' to be used to assess soil quality against a range of soil related functions. Soil quality in this context can be defined as the capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health habitation. 'Prompt values' were recommended for a set of indicators to be used within a tiered hierarchy. These indicators were chosen and assessed with consideration given to their costs and benefits. 'Prompt values' can be considered as values or ranges of values above or below which a level of change is understood to be critical in terms of the soil's fitness for a specific use. The 'prompt values' were based on scientific evidence, modelled datasets and, in some cases, expert opinion (Environment Agency, 2006b).

The soil indicators derived from this package of work comprised:

- Extractable phosphorous (Olsen P)
- Soil organic carbon (SOC)
- pH
- Bulk density
- Total nitrogen (N)
- Aqua regia extractable (that is, total) cadmium (Cd), copper (Cu), nickel (Ni) and zinc (Zn)

These indicators were primarily chosen for their role in indicating adverse effects upon the soil's function of environmental interaction[2]. This report focuses on the performance of the 'prompt values' for metals.

A number of other standards or 'prompt values' for soil metals currently exist in the scientific, policy and regulatory environments. For example, sewage sludge applications are not permitted on agricultural land where soil metal concentrations exceed specified values and metal additions must not exceed specific loading rates (Statutory Instrument (SI), 1989; Department of Environment (DoE), 1996). Indeed, the sludge limits are widely used across many regulatory regimes as *de facto* environmental limit values, covering a range of protection goals for which they were not originally derived. The sludge limit values for metals are different to the proposed soil indicator 'prompt values' from Environment Agency (2006b). These latter limit values were derived from the outputs of risk assessments performed under the EU regulation for existing substances (793/93/EEC) and incorporate soil specific consideration of bioavailability.

However, are these 'prompt values' better metrics for assessing the environmental and ecological risk of metals in soils than the sludge limit values? The uncertainties related

[2] From the six functions of soil: Support of ecological habitat and biodiversity; Food and fibre production; Environmental interaction; Providing a platform; Providing raw materials; and Protecting cultural heritage (from Blum 1993)

to the appropriateness of these soil limit values, in terms of fulfilling the regulatory regime requirements, can be addressed by undertaking appropriate and transparent validation exercises. It may seem incongruous, but very few limit values for metals used by jurisdictions across the world for environmental and ecosystem protection have been validated. Validation or 'road testing' in this sense meaning an assessment in the field, in order to establish whether the protection goal for which the limit value was set is achieved (Bright *et al*., 2006). For example, if the limit value for a metal has been established in order to protect soil fertility, then by using a number of established biological metrics of soil fertility on a range of soils that have historically received metal inputs under the specific regime of interest, it is possible to assess the merit of the limit value in relation to the protection goal (De Jong *et al*., 2007).

There is a clear need to assess the effectiveness of both the established limit values and the proposed 'prompt values' to fulfil their soil protection requirement in terms of soil fertility, biology and sustainability. This was the key objective of this project.

2.2 Legislative framework for organic material applications to agricultural land

Organic material applications to land are controlled on a sector-by-sector basis, where the policy instrument used (legislative or voluntary) may directly or indirectly impact on the resulting metal concentration of the soil.

- Sewage sludge (biosolids) is the most highly regulated material, with applications having to comply with specified maximum permitted soil metal concentrations and metal addition rates (SI, 1989; DoE, 1996).

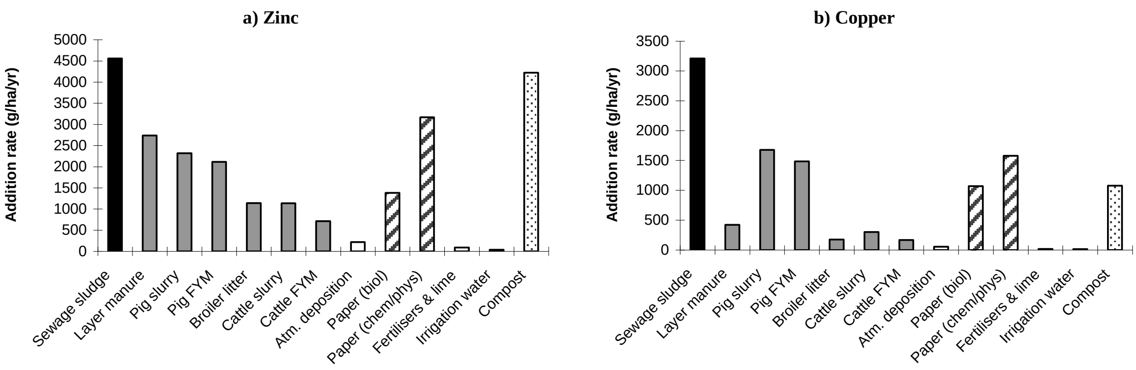
- Farm manure applications are controlled on the basis of the amount of nitrogen (N) applied. Outside Nitrate Vulnerable Zones (NVZs), applications of spread manure should comply with the advisory limit specified in the Code of Good Practice for the Protection of Water (Ministry of Agriculture, Fisheries and Food (MAFF), 1998a) of 250 kg total N/ha. However, within an NVZ (currently approximately 55 per cent of agricultural land in England and approximately 3 per cent in Wales), the nitrogen loading (that is, the nitrogen from spread manure plus that deposited by grazing livestock) must not exceed 250 kg N/ha on grassland and 170 kg N/ha on arable land (Defra, 2002), although the grassland nitrogen loading limits are likely to be lower in future. Note: sewage sludge and other organic material applications within an NVZ must also comply with these nitrogen loading limits. There are also metal recommendations in the Defra Soil Code (MAFF, 1998b), although these are directed at soils naturally high in metals and are related to direct toxic effects on plants and animals.

- Composts can be applied to agricultural land under a paragraph 7A exemption to the Waste Management Licensing Regulations (WMLR) (SI, 2005). As a result of the Quality Protocol (Waste and Resources Action Programme (WRAP), 2007), source segregated compost applications can be made to agricultural land outside the WMLR provided that they comply with the Quality Compost protocol specifications.

- Dredgings (such as from canals, rivers and so on) can be applied to soils under a WMLR exemption (SI, 2005), although they are not strictly organic materials. Analysis of canal sediment samples shows that they typically comprise approximately 96 per cent mineral material, similar to mineral topsoils, and add significantly to the soil volume; that is, they act as soil forming materials rather than an organic fertiliser/source of nutrients.

The differences between rules governing the application of different organic and inorganic materials to agricultural land are important. This is because metal loading rates to soils from a highly regulated material such as sewage sludge can be similar to those from materials such as pig slurry or green compost (Figure 1), where applications are controlled by different rules.

Figure 1. Zinc and copper loading rates to soils from different organic materials applied at a rate of 250 kg N/ha and other sources (Nicholson and Chambers, 2006).



2.3 Soil Monitoring

The UK, like many other EU member states, is committed to delivering a monitoring network to assess soil quality. Indeed, Action 11 of “The First Soil Action Plan for England: 2004-2006” (Defra, 2004) states that Defra will work “to identify the indicators which should be built into a national soil monitoring scheme …which meets both national and European requirements”. Furthermore, the Environment Agency has made a commitment to deliver robust indicators and ‘prompt values’ to assess soil quality. Soil quality has traditionally been assessed within an agricultural context, with little application to soils in semi-natural or low nutrient systems. The soil indicators developed by the Environment Agency (2006b) need to be validated beyond modelled scenarios and the academic literature to determine whether they fulfil the requirement as appropriate ‘prompt values’ for potential ecological risk.

2.4 Environmental Protection Act

The ecological risk assessment of soils at sites contaminated through historic pollution is driven, in part, through requirements under Part 2a of the Environmental Protection Act. Soil Screening Values (SSVs) developed to help the assessment of ecological risk have yet to be fully validated and are currently seen by practitioners as too precautionary, with too little guidance on use and interpretation. The Environment Agency plans to go out to final consultation on the derivation of the proposed SSVs in mid-October 2008. The ‘road testing’ will further assess the effectiveness of these screening values, which are the same as the ‘prompt values’ for the metals considered here.

This project has not considered Soil Guideline Values (SGVs), which were derived using the Contaminated Land Exposure Assessment (CLEA) model for three land uses: residential (with and without vegetable-growing), allotments and commercial/industrial. SGVs represent ‘intervention values’, which if exceeded, may indicate that further investigation and/or remedial action may be required to protect human health (the values are not intended to be protective of soil quality or function).

2.5 Integrated Pollution Prevention and Control (IPPC).

For the majority of industrial activities regulated under PPC[3], direct release of polluting substances to land will not be permitted. There are certain activities covered by the PPC regulations where direct releases are unavoidable, such as slurry spreading in the intensive livestock sector and landfilling operations. Risk assessment for the former is addressed, and release to land outside the installation boundary from the latter is prevented by the requirements of the Landfill & Ground Water Directives implemented in the conditions of the PPC permit. The assessments of impacts from PPC-regulated processes as a result of indirect deposition from air releases to land are addressed in H1 guidance.

There are currently no Environmental Quality Standards in the UK for releases to land by deposition and very little information is available from any source on suitable benchmarks. Where maximum deposition rates have been generated, for example critical loads for sulphur and nitrogen, this has taken many years of scientific effort. The current method is an interim system to be used while a more robust suite of environmental benchmarks is developed.

2.6 Summary

Metals can enter soils through a number of pathways, including addition of organic materials used as soil conditioners/nutrient sources (such as biosolids, livestock manures, composts), the use of inorganic fertilisers and lime, ‘growing medium’ additions (canal dredgings, for example) and via deposition from the atmosphere. These additions are governed by a number of legally binding regulations and voluntary guidelines, which either directly or indirectly control the inputs of metals to soils. The drivers for these regulations and guidelines are understandably different, as are some of the protection goals. Indeed, the standards set may have implications not just for soil quality, but also for air pollution, water quality and so on. However, the question remains as to whether the current limit values for metals appropriately account for these differences and whether the alternative ‘prompt values’ recommended to assess soil quality (the SSVs) are any more or less effective?

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[3] This was combined with the Waste Management Licensing Regulation in April 2008 to create the new Environmental Permitting Regime.

3 Aims and Objectives

3.1 Aims

This project aimed to validate (‘road test’) existing soil metal limit values and proposed soil ‘prompt values’ in terms of their effectiveness and practicality on a range of soils falling under different soil-related regulatory regimes. The ‘effectiveness’ was gauged in terms of whether the limit values were predictive of risk conditions for soils for which secondary data on soil biological process were also available. The information collected through this work will be used to facilitate the development of evidence-based policy and guidance to help ensure the sustainable use of soil resources in the UK, and also to inform current and future policies related to metals risks in soils. This is the first time soil limit values for metals will have been validated in this way.

3.2 Objectives

The principal objectives were to:

- Use existing soils data from well-characterised sites across Britain to assess whether existing metal limit values and ‘prompt values’ were predictive of adverse soil conditions or management.

- Determine the balance and the occurrence of situations where a regime was over- or under-protective of the soil.

- Determine whether the scientific approach to each regulatory regime (despite their differing goals) delivered consistent answers in terms of potential metal risk.

- Assess the practical application and usability of the suggested ‘prompt values’ for metals in each regulatory regime, with a view to providing guidance on usage and interpretation.

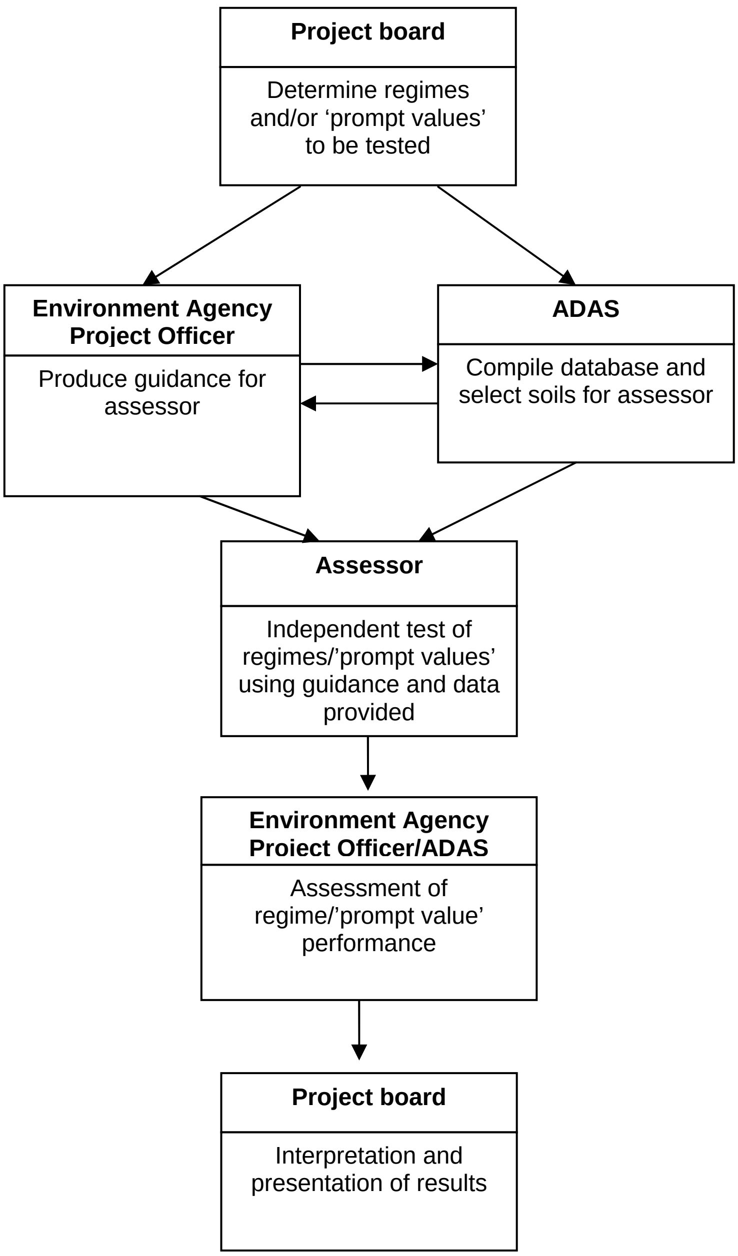
4 Approach and methodology

The project was divided into two phases. In Phase I, the project methodology was developed, and validation ('road testing') of the regimes and limit values for metals was undertaken. In Phase II, the 'road testing' methodology was extended to cover the other identified soil quality indicators (Environment Agency, 2006b). This report covers the work undertaken during Phase I on metals.

4.1 Approach

The project board held two initial meetings to discuss the regimes to be tested for the metals work and to confirm the broad methodology that would be used for the 'road testing' process. A summary of the steps involved in the process is shown in Figure 2.

Figure 2. Steps taken to 'road test' the metal regimes and 'prompt values'.



4.2 Methodology

4.2.1 Regimes tested

The most important current regulatory regimes for which the ‘road testing’ of potential indicators and ‘prompt values’ for metals would be pertinent are outlined below. The commonality in all these regimes is the need to judge the condition or quality of soil at a specific location. All rely on site-specific measurements of total soil metal concentrations and comparison against numerical limit values, considering, to a greater or lesser extent, other soil physico-chemical conditions (such as pH). It is imperative that the metrics used to perform this judgement are scientifically robust and consistent across regimes. A further consideration is that some of the regimes listed use the indicators and ‘prompt values’ as part of a tiered framework, such that if a trigger is exceeded, then further investigation and information needs to be collected.

A brief summary of the regime protection goals is given together with maximum permissible limits in soils (where appropriate) and a description of the processes by which soils data are manipulated in order to allow the decision to be taken.

Note: the Project Board agreed that the IPPC Regulations were to be excluded from the list of regimes tested, as an interim approach was currently being employed based on the current UK Sewage Sludge Regulations and Code of Practice (see section 2.5).

The Sludge (Use in Agriculture) Regulations (1989). This regulation (SI, 1989) aims to protect the environment, in particular the soil, when sewage sludge is used in agriculture. It states that sludge should be used “to prevent harmful effects on soil, vegetation, animals and man”, that account is taken of the nutrient needs of the plants, and that the quality of the soil and of surface- and groundwaters is not impaired. The metal limit values are given in Table 1. Note that for zinc, copper and nickel, the limit values are related to the measured soil pH.

Table 1. Maximum permissible total metal concentrations (mg/kg dry weight) in sludge amended soils (SI, 1989)

		Soil pH		
	5.0<5.5	5.5<6.0	6.0-7.0	>7.0
Zn	200	250	300	450
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

The Code of Practice for Agricultural Use of Sewage Sludge (1996). The key difference between the 1989 Sludge Regulations (SI, 1989) and the Code of Practice for Agricultural Use of Sewage Sludge (DoE, 1996) is that the limits for soil zinc were reduced as a ‘precautionary measure’ in accordance with the recommendations of an Independent Scientific Committee review of the “Soil Fertility Aspects of Potentially Toxic Elements” (MAFF, 1993; Table 2).

Table 2. Maximum permissible total metal concentrations (mg/kg dry weight) in sludge amended soils (DoE, 1996)

	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

*Advisory limit

EC 'Working Document on Sludge' 3rd Draft (2000). This document (EC, 2000) states that the use of sewage sludge is to be undertaken in such a way as to minimise the risk of negative effects on human, animal and plant health; the quality of groundwater and/or surface water; the long-term quality of the soil, and the biodiversity of the microorganisms living in the soil. This document was produced as a technical (discussion) document and has no regulatory or guidance status. The suggested limit values shown in Table 3 are considerably lower than those currently in use in the UK and many other EU countries

Table 3. Maximum permissible total metal concentrations (mg/kg dry weight) in sludge amended soils (EC, 2000)

	Soil pH		
	5.0<6.0	6.0<7.0	≥7.0
Zn	60	150	200
Cu	20	50	100
Ni	15	50	70
Cd	0.5	1	1.5
Pb	70	70	100
Hg	0.1	0.5	1

Quality Compost Protocol. The Quality Compost Protocol (WRAP, 2007) specifies that source-segregated quality compost can be used in agriculture and soil-grown horticulture as a soil 'improver or mulch' provided it does not pose a risk to human health or the environment, and its use does not compromise the future sustainable use of the soil. Metal analysis of the soil is required prior to the first application of compost and again when predicted concentrations approach 75 per cent of the limit values, which are the same as those set out in the "Code of Practice for Agricultural Use of Sewage Sludge" (DoE 1996, Table 2).

Waste Management Licensing Regulations. The spreading of industrial 'wastes' on agricultural land is controlled by the Waste Management Licensing Regulations[4] - WMLR (SI, 2005) - and must be shown to provide "benefit to agriculture or ecological improvement" under a WMLR exemption. Definitions of agricultural benefit or ecological improvement are not given in the legislation, but statutory guidance indicates that the 'waste' going to land must serve a useful purpose by replacing substances that otherwise would have been used for that purpose (for example, replacing the need for manufactured fertiliser or lime applications). Such exemptions are needed when recycling composts (outside the Quality Compost Protocol), canal dredgings, paper crumble, food/drink processing 'wastes' and so on. According to technical guidance, the application of these materials must not cause the concentration of any metals in soils to exceed the specified limits in the Code of Practice for Agricultural Use of

[4] This has now been combined with PPC to create the Environmental Permitting Regime.

Sewage Sludge (DoE 1996, Table 2). Other controls are also applied on a waste by waste/site by site basis.

BSI Topsoil. The British Standard for Topsoil (BSI, 2007) specifies requirements for topsoils that are moved or traded and is not intended (or appropriate) for the grading, classification or standardisation of topsoil or subsoil that remains *in situ*. It stipulates that multipurpose topsoil should be capable of supporting grass, trees, shrubs and other plantings. Two categories of contaminants are identified, with a requirement to use the more sensitive limit for any contaminant that appears in both categories:

- 'Phytotoxic contaminants' are specified as zinc, copper and nickel for which the limits are the same as those specified in the Code of Practice for Agricultural Use of Sewage Sludge (DoE 1996, Table 2). Thus in this regime, the limit values from DoE (1996) which aim to protect soil (and water) quality are actually used to protect only against phytotoxicity (that is, whilst the limit values are the same, the regime protection goals are different).
- The other category is 'chemical contaminants' for which no numerical values are given but it is stated that concentrations 'shall not present excessive risk to human health or the environment' and should not exceed those permitted by current UK legislation. The list of contaminants to be analysed is based on the history of the source material and the intended end use. Thus the soil could also be analysed for cadmium and lead. As there are currently no other published limits for these metals, by default the values in Code of Practice for Agricultural Use of Sewage Sludge (DoE 1996; Table 2) are again used.

UK Soil Screening Values (SSVs) and UK Soil Indicators Consortium (UKSIC) Prompt Values - EU Risk Assessment Values. The values the Environment Agency is proposing to use as soil screening values (SSVs) in the Contaminated Land regime (under Part 2a of the Environment Protection Act 1990) and as 'prompt values' in assessing UK Soil Quality (Environment Agency, 2008), are based on the values derived under the auspices of the EU Existing Substances Regulations (Directive 98/8/EC) and are predicted no-effect concentrations (PNECs) based on soil ecotoxicological test data. Therefore, these three sets of values are effectively the same, and will be referred to throughout the rest of the report as EU Risk Assessment Values[5]. The values are (bio)availability-based, and represent a step change in the way in which ecological risks from metals in soils are assessed (Smolders *et al*., 2004; Rooney *et al*., 2006; Broos *et al*., 2007).

The EU Risk Assessment approach considers that the ecotoxicity of metals to soil organisms is dependent on soil physico-chemistry (pH, cation exchange capacity - CEC, and so on) and contact time between the metal and the soil (reduction of bioavailability over time). For data rich metals such as copper, nickel and zinc the methodology uses metal specific regression relationships derived from laboratory and field-based ecotoxicity data to derive predicted no effect concentrations (PNEC)(as total metal concentration) relevant for the field. These are then compared with the measured total metal concentrations in the field. If the field measured value divided by the PNEC is greater than unity, then there is a potential risk from that specific metal under those soil conditions (Netherlands 2006; ECI 2007; Denmark 2007; LDAI 2007; Belgium 2007). For lead and cadmium, there is less data available and the full site-specific corrections cannot be made. The soil properties on which normalisation of

[5] Since completion of this work, the Environment Agency has reviewed the SSVs and modified some of the calculations for these values in accordance with decisions taken with regard to for example the use of background values. Therefore the values used in this report are not final. The current proposed SSVs can be found in the 'Guidance on the Use of Soil Screening Values for Ecological Risk Assessment', Environment Agency 2008 (SC070009/SR2b).

ecotoxicity data (plants, microbial function and invertebrates) is based are given in Table 4. Values for a typical set of soil conditions are given for copper, nickel and zinc, along with the 'prompt values' for cadmium and lead, in Table 5. The site-specific considerations of copper, nickel and zinc (bio)availability can now be run sequentially in an Excel-based decision tool developed by the Environment Agency and the Belgium-based consultancy EURAS.

Table 4. Abiotic factors considered in the PNEC calculations for the EU Risk Assessment of zinc, copper, nickel, cadmium and lead (See individual risk assessment reports for details)

	Leaching/ ageing factor	Microbes	Plants	Invertebrates	PNEC calculation	Assessment factor
Zn	3	Background	CEC and pH	CEC	Based on HC5 for combined dataset[1,2]	1
Cu	2	OC and Clay[3] pH and CEC[4]	-	CEC	Based on HC5 for combined dataset [1]	1
Ni	Variable with pH	-	-	CEC	Based on HC5 for combined dataset [1]	2
Cd	-	-	-	-	Based on median HC5 from microbial, fauna and plant SSDs	2
Pb	1 – 4.2	-	-	-	Based on HC5 for combined dataset [1]	1

[1] HC = hazardous concentration below which 5% of species are affected. Based on combined dataset for microbes, plants and invertebrates
[2] This differs from the original EU Risk Assessment for zinc, which estimated one species sensitivity distribution (SSD) for microbes and another for plants and invertebrates, but is in line with the new methodology used for copper and nickel, which combines these dataset to estimate one SSD only.
[3] For studies measuring microbial biomass, SIR (substrate induced respiration) or glutamic acid
[4] For microbial studies measuring microbial respiration

Table 5. 'Prompt values' for a typical soil (mg/kg dry weight)

Metal	Prompt value
Cd	1.1
Cu	58*
Ni	21*
Pb	260.7
Zn	149*

*These are for a soil of pH 6.5, organic matter of 2% and clay content of 10%.

4.2.2 Regime protection goals

Comparing the performance of regulatory regimes is only justified if they have similar protection goals. Table 6, which summarises the key protection goals of the regimes studied in this project, indicates that there was broad comparability across the regimes.

Table 6. Summary of regime protection goals

Regime	Key Protection Goal
Sludge (use in Agriculture) 1989	"Prevent harmful effects on soil, "prevent harmful effects on soil,
EC Sludge 3rd working draft (2000)	"Minimise the risk of negative effects on human, animal and plant health, long-term soil quality….and biodiversity of soil micro-organisms."
Waste Management License Regulations	"Without risk to water, air, soil and plants and animals."
Compost Quality Protocol	"Must not compromise the future sustainable use of soil."
EU Risk Assessments and UK SSVs	"Afford a level of protection to terrestrial species and critical ecological functions."

Implementing protection goals in a regulatory framework requires the identification of *assessment endpoints* – in effect, measurements that can be interpreted in terms of the protection goals. The data sets used in this study employed measurements on plant yield, plant cadmium content, the size of the soil microbial biomass, the activity of specific microbial communities (that is, nitrification), and the number of free-living rhizobia. All these are directly interpretable in terms of the protection goals listed above.

4.2.3 Selection of soils data

Soils data were collated from a number of field experiments conducted in Great Britain since the early 1990s, where applications of organic manures (sewage sludge, farm manure, green compost, paper crumble) had been made, and where these had elevated the soil metal concentrations compared with background metal concentrations at the site. Soils were selected for inclusion in the database where there was experimental data on soil metal concentrations and other soil properties required by the specific regimes, such as pH, organic matter and clay content. In addition, each selected soil had supplementary data available on one or more biological effects measured at the site (such as grain metal concentration, earthworm numbers, soil microbial biomass), which were not required by the regime *per se*, but could help to determine whether there had been detrimental effects to the soil at that site following the addition of metal-containing organic materials. Data were only included where it was possible to measure a significant ($p<0.05$) change in the biological property relative to the control soil, or where a biological property exceeded a specified limit (for example, if the measured wheat grain cadmium concentration was greater than 0.2 mg/kg). Soils from the following experiments were selected for inclusion in the database.

Long-term sludge experiments – LtSEs (Defra project SP0130). Metal-rich sludge cakes and metal-amended liquid sludges were applied to nine sites in Britain over a four-year period (1994-97) to establish individual metal (zinc, copper and cadmium) dose-response treatments (Gibbs *et al.,* 2006a; Gibbs *et al.,* 2006b). Data from all sites (except Auchincruive, where there was some uncertainty over the background soil copper concentration) were included in the database. The additional biological data collected were crop yields, wheat grain cadmium concentration, rhizobia most probable number (MPN), soil microbial biomass and respiration rate.

Metal salts experiment (Defra project SP0133). Inorganic metal salts were applied at three sites in England over a four-year period (1994-97) to establish individual metal (zinc, copper and cadmium) dose-response treatments (Gibbs *et al.*, 2003). The additional biological data collected were the same as the LtSEs (see above).

Historic sewage sludge experiment. Data were available from two arable sites at ADAS Gleadthorpe (Nottinghamshire) and Rosemaund (Herefordshire). At Gleadthorpe, sewage sludges enriched with salts of zinc, copper and nickel were applied to the loamy sand textured soil in 1982, with further metal rich sludge cake added to selected treatments in 1986. At Rosemaund, sewage sludges contaminated with zinc, copper, nickel and chromium were applied from 1968-1971 to a sandy loam textured soil (Bhogal *et al.*, 2003). The additional biological data collected were crop yield, wheat grain cadmium concentration, respiration rate, potentially mineralisable nitrogen (PMN), and earthworm and enchytraeid numbers (selected treatments only).

SOIL-QC (Defra project SP0530). Experimental sites at ADAS Gleadthorpe (Nottinghamshire), ADAS Terrington (Lincolnshire), ADAS Bridgets (Hampshire) and Harper Adams College (Shropshire) received repeated applications of farm manures for up to10 years and, more recently, additions of green compost and de-inked paper crumble (Bhogal *et al.,* 2006). The additional biological data collected were crop yield, soil microbial biomass, respiration rate, PMN, potentially mineralisable sulphur (PMS), and earthworm and nematode numbers.

HGCA grain survey. Paired soil and grain samples were collected from several hundred fields in Britain over three harvest seasons (Adams *et al*., 2004; Zhao *et al.*, 2004). The additional biological data collected were wheat and barley grain cadmium and lead concentrations.

Details of plot sizes and soil sampling protocols for each experiment are given in Table 7. Soil metal concentrations were determined by aqua regia or perchloric-nitric acid digestion and graphite-furnace atomic absorption spectrometry (GF-AAS) or ICP-MS. Unless otherwise stated, soil pHs are in water (1:2.5 w/v). Full details of the experimental design and analytical methods are available in the published references supplied for each experiment.

Table 7. Experimental plot sizes and sampling protocols.

Experiment name	Soil no.*	Plot size (m^2)	No of repli-cates	Samplin g depth (cm)	Sampling protocol
LtSE (cake)	1-185	48	3	25	Bulked 15 cores in W or regular grid.
LtSE (liquid)	186-248	4.2	3	25	Bulked 10 cores in W pattern
LtSE (metal salt)	249-271	4.2	3	25	Bulked 10 cores in W pattern.
Historic sludge	272-287	1.4	4	15	Bulked 10 cores in W pattern
Soil-QC	288-297, 508-514	45-300	3	15	Bulked 25 cores in W pattern.
HGCA grain survey	298-507	1	1	15	Quadrat placed at random in a field. Bulked 15 cores.

*Number assigned on the soils database

4.2.4 Soils database

The soils database contained details of the site's geographical location, soil texture, sampling technique (for example, depth of soil sampled, number of samples taken), experimental design (for example, number of replicates, plot area) and all soil physical, chemical and biological properties for which data were available. At most sites, there was more than one experimental treatment, so the database was structured in such a way as to provide one record per treatment (that is, each treatment was considered to be a soil scenario). Where there was data for more than one year, only the most recent was included. The final database contained details of more than 500 field soils. A summary of the ranges of soil metal concentrations and other soil properties in the database is given in Table 8.

The database was supplemented with comments where the observed biological effects indicated 'failure', that is, where detrimental effects of an organic material addition had been observed. A soil was deemed to have failed based on the biological criteria if one or more of the following effects were observed:

- The wheat grain cadmium or lead concentration exceeded the EU limit (0.2 mg/kg fresh weight - fw); EC (2001).
- There was a significant ($p<0.05$) reduction in microbial biomass and/or rhizobia numbers.
- There was a significant ($p<0.05$) increase in respiration rate.
- There was a significant ($p<0.05$) reduction in crop yield.
- There was a significant ($p<0.05$) reduction in earthworm, nematode or enchytraeid numbers

It should be emphasised that in this project a statistically significant change ($p<0.05$) in a biological measurement (compared with the control) was used to indicate that a soil had 'failed'. However, this may not necessarily indicate that there was a detrimental effect on the soil function. For example, there may have been a significant reduction in microbial biomass size, but only by 10 per cent of the value measured on the control soil. There is no clear evidence as to whether a 10 per cent reduction in biomass is in fact ‘harmful’, or what magnitude of change in the biological parameter should be considered unacceptable.

Table 8. Summary of the soil metal concentrations and other soil properties in the soils database

	Minimum	Maximum	Limit*	Count
Zn (mg/kg)	23	474	200	302
Cu (mg/kg)	4**	373	135	302
Cd (mg/kg)	<0.1	33	3	512
Pb (mg/kg)	7	783	300	245
Ni (mg/kg)	3	80	75	74
pH	5.4	8.5	-	514
OC (%)	<1	14	-	514
Clay (%)	6	30	-	304

*Limit value in the Code of Practice for Agricultural Use of Sewage Sludge for soils of pH 6.0-7.0 (DoE, 1996)
**Excluding data from the Auchincruive sludge cake site

4.2.5 Selection of data for the assessor

The Project Board initially decided to select 53 soils from the database for detailed assessment by the independent assessor (see Section 4.2.6). The subset of 53 study soils were not chosen at random but were selected to ‘test’ the regimes, with the soils selected including different soil textures and geographic locations. An attempt was also made to include a range of soil metal concentrations and soil pHs, such that for each metal (where possible) there were soils that were below, above or at the limits specified by the different regimes. Also, a roughly equal number of soils ‘passing’ or ‘failing’ based on the biological criteria were chosen.

The assessor was given a subset of the information on the database consisting of only the minimum data required to assess a soil against the above regimes (that is, soil metal concentration, background soil metal concentration at the site, pH, organic matter content, clay content). For some soils, a complete set of data was not available (for example, there was no measurement of soil nickel concentration).

Subsequently, it was decided to include all soils that were deemed to have ‘failed’ based on one or more of the biological criteria in the assessment. Thus, all potential instances within the database where the regimes were not sufficiently protective would be captured as part of the ‘road testing’ exercise. (*NB. This approach would not account for all instances where the regimes were over-protective*). This increased the number of soils assessed to 95, with the assessment of the additional soils undertaken at a later date by ADAS and the Environment Agency project officer. The data provided for the assessment exercise are given in Table 9.

4.2.6 Scenario testing

The testing of the metal ‘prompt values’ within the context of the regimes was undertaken by an independent scientist (Dr. Rob Parkinson, University of Plymouth) appointed by the project board.

A ‘generic’ guidance note was prepared for the assessor comprising information on the regimes to be tested and detailed work instructions (see Appendix I). This guidance note contained the standards and guidelines against which the assessor was required to judge the data. In addition, the guidance note provided information for each regime on the protection goals and how the soils data was to be used.

A spreadsheet was specially developed for this project by the Environment Agency and EURAS, and modified for use in the UK to allow the assessor to more easily apply the tiered approach required to use the EU Risk Assessment Values and the UK Soil Screening Values. In addition, a ‘detailed’ guidance note was written for the assessor explaining how to use and interpret the results of this spreadsheet (see Appendix II).[for Zn error found in the spreadsheet for version June 2007 used for Cu, Ni and Cd by independent assessor and ADAS/EA project officer, then EURAS v. 14 for Zn.]

The assessor was asked to produce a report in two sections. The first section consisted of a summary table for each of the 53 soils and respective regimes, indicating whether each soil had passed or failed each regime and on which metal(s) it had failed. The second section was a narrative addressing the reasoning behind decisions made in the summary table. The aim of the report was to present the results of the assessments and to provide a judgement as to whether the protection goals for each of the respective regimes were met. The assessor was specifically asked to cover issues such as:

- Are the standards effective in achieving the protection goals for the regime?
- Is this process practical to follow and understand?
- How much expert judgement is needed in making the decision?
- How much time did each regime require to perform the assessment on the soils?
- What would make the processes clearer/understandable or more robust?

Table 9. Soils data provided for regime assessment

					Soil metal concentrations (mg/kg dry matter)									
Soil No.	**Soil text-ure***	**Clay (%)**	**OM (%)**	**pH**	**Back-ground Zn**	**Total Zn**	**Back-ground Cu**	**Total Cu**	**Back-ground Ni**	**Total Ni**	**Back-ground Cd**	**Total Cd**	**Back-ground Pb**	**Total Pb**
4	sl/ls	7	3.3	5.9	35.1	134.8	11.1	52.9			0.20	0.20		
9	sl/ls	7	3.6	5.9	35.1	79.9	11.1	138.2			0.20	0.50		
11	sl/ls	7	3.3	5.9	35.1	182.0	11.1	215.7			0.20	0.44		
13	sl/ls	7	4.7	5.8	35.1	209.0	11.1	69.4			0.20	2.53		
44	zcl/zc	30	4.9	6.4	48.2	136.6	10.8	44.1			0.86	1.40		
50	zcl/zc	30	4.9	6.5	48.2	98.0	10.8	146.9			0.86	1.37		
51	zcl/zc	30	4.5	6.4	48.2	87.1	10.8	170.8			0.86	1.13		
54	zcl/zc	30	5.5	6.5	48.2	119.5	10.8	50.5			0.86	2.70		
55	zcl/zc	30	5.4	6.5	48.2	136.6	10.8	52.6			0.86	3.76		
64	scl/scl	21	8.6	5.8	81.0	166.0	24.1	61.8			0.31	0.50		
74	scl/scl	21	8.0	5.7	81.0	162.1	24.1	72.0			0.31	3.12		
75	scl/scl	21	8.1	5.6	81.0	177.1	24.1	72.2			0.31	4.03		
78	scl/scl	21	5.8	5.7	81.0	161.2	24.1	38.1			0.31	0.43		
81	cl/sl	23	6.4	6.4	100.4	100.4	13.6	13.6			0.41	0.41		
104	zcl/zl	25	4.4	6.7	71.5	136.9	18.5	46.5			0.30	0.42		
109	zcl/zl	25	3.8	6.6	71.5	88.6	18.5	81.1			0.30	0.30		
128	cl/cl	20	5.1	7.8	52.0	250.0	14.0	58.7			0.45	0.89		
133	cl/cl	20	5.0	8.0	52.0	82.3	14.0	105.7			0.45	0.48		
143	cl/cl	20	4.7	7.8	52.0	150.0	14.0	38.7			0.45	0.64		
145	cl/cl	20	4.3	7.8	52.0	52.5	14.0	28.3			0.45	1.50		
150	sl/cl	16	4.1	6.5	44.7	180.0	10.6	53.7			0.29	0.66		
152	sl/cl	16	3.9	6.6	44.7	350.0	10.6	74.3			0.29	1.03		
160	sl/cl	16	4.8	6.7	44.7	113.3	10.6	53.7			0.29	3.50		
163	sl/cl	16	2.9	6.7	44.7	87.0	10.6	23.0			0.29	0.37		
179	ls/sl	8	2.9	6.8	46.6	108.6	13.2	55.7			0.50	2.37		
195	zcl/zl	25	2.6	6.7	64.3	52.3	12.7	15.3			0.31	1.93		
196	zcl/zl	25	3.2	6.6	64.3	58.0	12.7	16.0			0.31	1.97		
210	ls/sl	8	1.8	6.8	48.6	202.4	11.4	22.3			0.20	0.51		
216	ls/sl	8	1.6	6.8	48.6	61.6	11.4	24.1			0.20	1.86		
217	ls/sl	8	1.7	6.9	48.6	59.7	11.4	25.0			0.20	3.15		
229	sl/cl	16	1.9	6.9	50.7	50.7	20.7	20.7			0.64	0.64		
251	ls	6	2.1	6.4	39.0	50.2	10.1	12.6	4.8	4.9	0.18	0.27		
255	ls	6	2.4	5.9	39.0	397.5	10.1	20.6	4.8	5.8	0.18	0.87		
258	ls	6	2.4	5.7	39.0	206.0	10.1	132.5	4.8	6.8	0.18	0.54		
263	ls	6	2.6	5.7	39.0	63.3	10.1	373.0	4.8	6.1	0.18	0.25		
274	sl	14	2.4	6.9	72.6	74.3	36.6	22.8	14.1	15.6	0.25	0.58		
278	sl	14	2.5	6.6	72.6	195.5	36.6	205.8	14.1	22.7	0.25	0.68		
279	sl	14	2.3	6.9	72.6	148.5	36.6	31.5	14.1	62.8	0.25	0.58		
280	sl	14	2.3	6.8	72.6	158.5	36.6	36.3	14.1	78.9	0.25	0.48		
282	sl	14	2.5	7.0	72.6	126.8	36.6	33.0	14.1	22.8	0.25	1.85		
286	sl	14	2.5	6.8	72.6	186.0	36.6	29.5	14.1	79.5	0.25	1.18		
287	sl	14	2.6	6.9	72.6	114.0	36.6	28.2	14.1	30.9	0.25	1.44		
288	ls	6	1.2	6.0	22.5	22.5	4.0	4.0	4.1	4.1	0.05	0.05	16.20	16.2
291	ls	6	1.6	6.3	22.5	30.3	4.0	5.2	4.1	4.6	0.05	0.05	16.20	15.4
341	scl	20	8.8	7.8								0.27		335.2
445	scl	20	7.5	7.7								1.98		146.1
447	sl/scl	17	11.4	6.6								33.03		435.8
458	ls	6	4.5	7.5								6.35		84.8

*sl = sandy loam, ls = loamy sand; cl = clay loam; scl = sandy clay loam; zl = silt loam; zc = silty clay; zcl = silty clay loam

Table 9 (cont.). Soils data provided for regime assessment

Soil No.	Soil text-ure*	Clay (%)	OM (%)	pH	Soil metal concentrations (mg/kg dry matter)										
					Back-ground Zn	Total Zn	Back-ground Cu	Total Cu	Back-ground Ni	Total Ni	Back-ground Cd	Total Cd	Back-ground Pb	Total Pb (
5	sl/ls	7	3.8	5.9	35.1	256.2	11.1	112.9			0.20	0.24		
6	sl/ls	7	3.5	5.9	35.1	347.2	11.1	90.7			0.20	0.33		
7	sl/ls	7	2.9	5.8	35.1	353.9	11.1	89.3			0.20	0.49		
10	sl/ls	7	3.0	5.9	35.1	123.7	11.1	171.9			0.20	0.46		
15	sl/ls	7	3.4	5.9	35.1	192.1	11.1	80.9			0.20	4.18		
45	zcl/zc	30	4.9	6.7	48.2	211.7	10.8	58.7			0.86	1.26		
46	zcl/zc	30	5.1	6.4	48.2	343.2	10.8	56.7			0.86	1.47		
65	scl/scl	21	11.8	5.9	81.0	281.1	24.1	82.3			0.31	0.75		
66	scl/scl	21	8.8	5.7	81.0	367.8	24.1	87.5			0.31	0.86		
67	scl/scl	21	9.2	5.7	81.0	473.6	24.1	110.6			0.31	1.06		
87	cl/sl	23	7.1	6.4	100.4	272.9	13.6	61.1			0.41	0.80		
95	cl/sl	23	8.1	6.4	100.4	175.1	13.6	59.2			0.41	4.19		
106	zcl/zl	25	3.7	6.5	71.5	284.1	18.5	71.2			0.30	0.75		
107	zcl/zl	25	3.6	6.7	71.5	335.4	18.5	83.8			0.30	0.85		
129	cl/cl	20	5.3	7.6	52.0	305.0	14.0	67.5			0.45	1.05		
140	cl/cl	20	5.3	7.8	52.0	160.0	14.0	53.0			0.45	3.40		
151	sl/cl	16	3.7	6.8	44.7	300.0	10.6	61.7			0.29	0.79		
156	sl/cl	16	4.0	6.6	44.7	57.7	10.6	153.3			0.29	0.33		
170	ls/sl	8	2.9	6.9	46.6	212.6	13.2	62.1			0.50	0.50		
171	ls/sl	8	3.1	6.8	46.6	273.3	13.2	75.6			0.50	0.65		
172	ls/sl	8	2.8	6.7	46.6	384.6	13.2	94.1			0.50	0.81		
176	ls/sl	8	2.8	6.6	46.6	86.4	13.2	192.3			0.50	0.50		
180	ls/sl	8	3.2	6.8	46.6	124.8	13.2	61.1			0.50	3.23		
204	sl/cl	16	2.8	6.9	47.4	48.8	12.5	99.5			0.35	0.38		
225	zcl/zl	25	2.9	6.5	74.3	91.7	17.8	133.5			0.37	0.47		
227	zcl/zl	25	3.1	6.5	74.3	76.0	17.8	18.8			0.37	2.29		
228	zcl/zl	25	3.0	6.5	74.3	70.5	17.8	16.4			0.37	2.57		
235	sl/cl	16	2.0	7.0	50.7	47.0	20.7	153.3			0.64	0.56		
245	ls/sl	8	1.7	6.8	56.3	46.2	13.2	185.6			0.20	0.41		
246	ls/sl	8	1.7	6.8	56.3	47.7	13.2	13.7			0.20	2.01		
247	ls/sl	8	1.6	6.7	56.3	45.4	13.2	12.8			0.20	3.51		
248	ls/sl	8	1.2	6.8	56.3	49.6	13.2	14.7			0.20	4.45		
250	ls	6	2.3	6.3	39.0	57.2	10.1	15.9	4.8	6.7	0.18	0.28		
254	ls	6	2.5	6.0	39.0	262.0	10.1	22.0	4.8	6.6	0.18	0.80		
256	ls	6	2.5	6.2	39.0	74.8	10.1	53.8	4.8	5.1	0.18	0.24		
257	ls	6	2.6	5.8	39.0	159.0	10.1	73.5	4.8	7.8	0.18	0.52		
259	ls	6	2.6	5.7	39.0	303.0	10.1	203.0	4.8	8.8	0.18	0.60		
260	ls	6	2.4	6.1	39.0	54.8	10.1	134.5	4.8	7.7	0.18	0.24		
261	ls	6	2.3	6.3	39.0	50.2	10.1	145.5	4.8	6.8	0.18	0.18		
262	ls	6	2.9	6.0	39.0	56.7	10.1	247.0	4.8	6.8	0.18	0.27		
265	ls	6	2.4	6.5	39.0	73.6	10.1	14.6	4.8	13.5	0.18	0.21		
267	ls	6	2.3	6.2	39.0	111.5	10.1	12.3	4.8	19.4	0.18	0.19		
270	ls	6	2.3	6.5	39.0	43.3	10.1	13.9	4.8	28.6	0.18	0.16		
271	ls	6	2.3	6.2	39.0	45.7	10.1	9.1	4.8	34.0	0.18	0.16		
285	sl	14	2.6	6.7	72.6	181.0	36.6	191.8	14.1	17.9	0.25	0.91		
423	ls	6	3.1	6.8								0.21		33.1
454	ls	6	3.6	7.6								16.38		70.0

*sl = sandy loam, ls = loamy sand; cl = clay loam; scl = sandy clay loam; zl = silt loam; zc = silty clay; zcl = silty clay loam

4.2.7 Assessing regime performance

On receipt of the summary table from the assessor, the results were matched against the prior assessments made as to whether the soils had passed or failed based on the observed biological effects (Table 10). This enabled the development of a regime performance table to highlight how successful each regime was at protecting the soil.

One of the following four performance categories was assigned:

- **PASS/PASS** – the soil was below the maximum permissible concentration (or 'prompt value') and no adverse biological effects were observed.
- **FAIL/FAIL** – the soil was above the maximum permissible concentration (or 'prompt value') and some adverse biological effects were observed.

For soils in these two performance categories, the regimes were *performing correctly*; that is, a correct prediction was made by the regime as to whether additions made to the soil had had harmful effects on soil function.

- **PASS/FAIL** – the soil was below the maximum permissible concentration (or 'prompt value'), but some adverse biological effects were observed.

For soils in the category, the regime was *not sufficiently protective* of the soil.

- **FAIL/PASS** – the soil was above the maximum permissible concentration (or 'prompt value'), but no adverse biological effects were observed.

For soils in this category, the regime was *overly protective* of the soil.

The metal or metals(s) that caused the soil to fail a regime were also recorded on the summary table. The assessment process is summarised in Figure 3.

Figure 3. Schematic showing the steps taken to assess regime performance

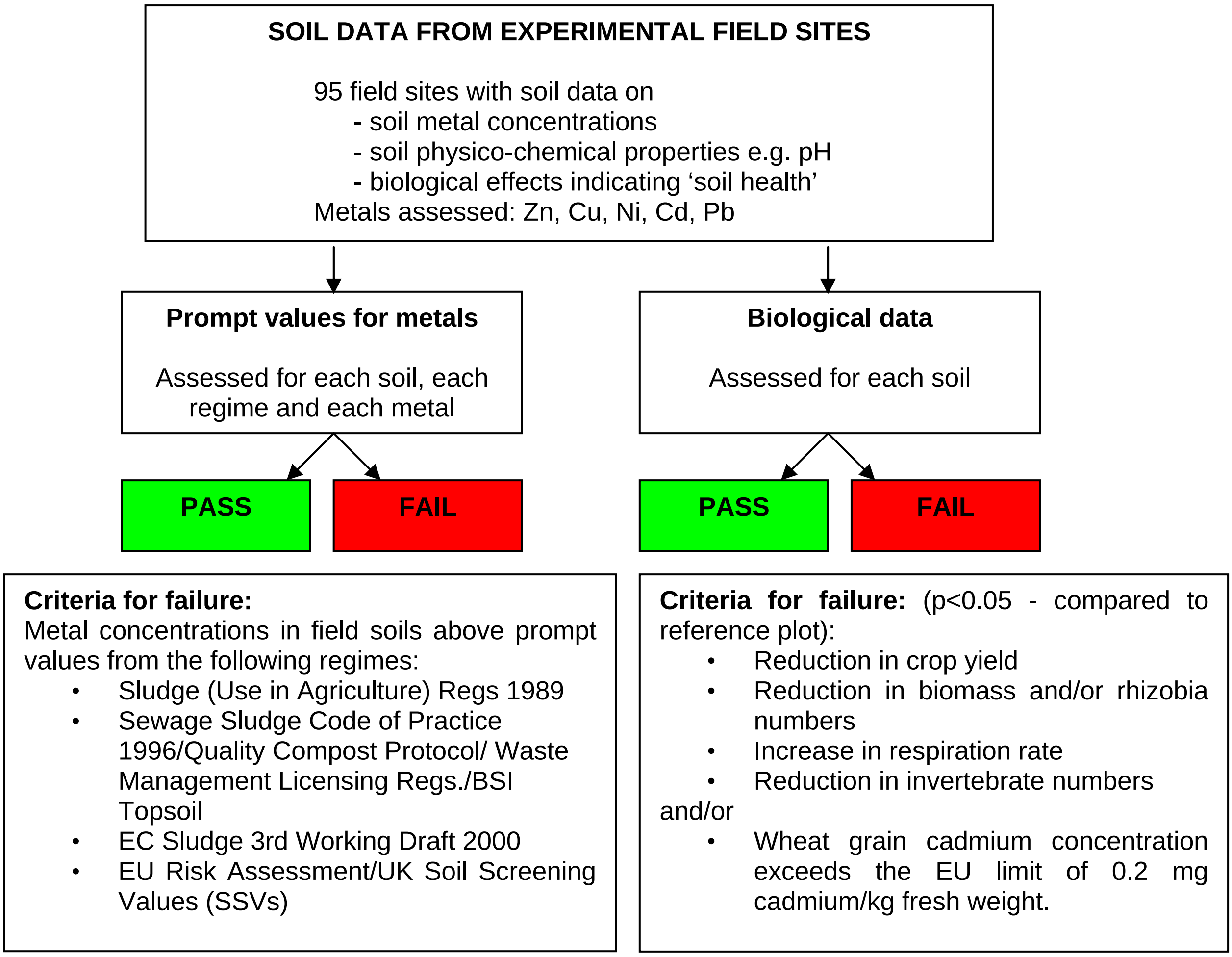


Table 10. Assessment of soils that passed or failed based on biological effects and details of the biological properties measured

Soil No.	PASS /FAIL	Microbila biomass C	Rhizobia numbers	Respiration rate	Wheat grain Cd*	Crop yield	Nematode numbers	Earthworm numbers	Enchytraied numbers
4	**F**	25% dec.	M	M	M	M			
9	**F**	26% dec.	M	M	M	M			
11	**F**	27% dec.	M	M	M	M			
13	**P**	M	M	M	M	M			
44	**P**	M	M	M	M	M			
50	**P**	M	M	M	M	M			
51	**P**	M	M	M	M	M			
54	**P**	M	M	M	M	M			
55	**P**	M	M	M	M	M			
64	**F**	M	3 log dec.	M		M			
74	**P**	M	M	M		M			
75	**F**	M	3 log dec.	M		M			
78	**F**	M	2.5 log dec.	M		M			
81	**P**	M	M	M		M			
104	**P**	M	M	M	M	M			
109	**P**	M	M	M	M	M			
128	**P**	M	M	M					
133	**P**	M	M	M					
143	**P**	M	M	M					

145	**P**	M	M	M					
150	**P**	M	M	M	M				
152	**F**	M	1.5 log dec.	M	M				
160	**P**	M	M	M	M				
163	**F**	26% dec.	M	M	M				
179	**F**	M	M	M	Exceeds limit				
195	**F**	M	M	M	Exceeds limit	M			
196	**F**	M	M	M	Exceeds limit	M			
210	**F**	37% dec.	1 log dec.	M	M				
216	**F**	M	M	M	Exceeds limit				
217	**F**	M	M	M	Exceeds limit				
229	**P**	M	M	M					
251	**P**				M	M			
255	**F**			M	Exceeds limit	Bean yield 8% of control.	26% of control.	M	16% of control.
258	**F**				Exceeds limit	Bean yield 17% of control.			
263	**F**			M	M	Bean yield 8% of control	M	13% of control	M
274	**P**				M	M			
278	**F**				M	Bean yield 80% of control			
279	**P**				M	M			
280	**P**				M	M			
282	**F**				Exceeds limit	M			
286	**P**				M	M			
287	**F**				Exceeds limit	M			
288	**P**	M		M		M	M	M	
291	**P**	M		M		M	M	M	
341	**P**				M				
445	**P**				M				
447	**F**				Exceeds limit				
458	**F**				Exceeds limit				

‘M’ indicates that a biological property was measured but no significant ($p<0.05$) effect was recorded, or the grain Cd limit was not exceeded.

*A soil failed if wheat grain Cd or Pb concentration exceeded the limit of 0.20 mg/kg fw (0.235 mg/kg dw at 85% dry matter; EC 2001)

Table 10 (cont.). Assessment of soils which passed or failed based on biological effects and details of the biological properties measured

Soil No.	PASS /FAIL	Microbial biomass C	Rhizobia numbers	Respiration rate	Wheat grain Cd*	Crop yield	Nematode numbers	Earthworm numbers	Enchytraied numbers
5	**F**	M	2 log dec.	M	M	M			
6	**F**	M	2 log dec.	M	M	M			
7	**F**	40% dec.	3 log dec.	M	M	M			
10	**F**	28% dec.	M	M	M	M			
15	**F**	M	1.5 log dec.	M	M	M			
45	**F**	M	1 log dec.	M	M	M			
46	**F**	M	1 log dec.	M	M	M			
65	**F**	M	4 log dec.	M		M			
66	**F**	M	4 log dec.	M		M			
67	**F**	M	4 log dec.	M		M			
87	**F**	M	2 log dec.	M		M			
95	**F**	M	1 log dec.	M		M			
106	**F**	M	2 log dec.	M	M	M			
107	**F**	M	2.5 log dec.	M	M	M			
129	**F**	20% dec.	M	M					
140	**F**	M	M	33% inc.					
151	**F**	M	1.3 log dec.	M	M				
156	**F**	33% dec.	M	M	M				
170	**F**	M	2.2 log dec.	M	M				
171	**F**	47% dec.	1.9 log dec.	M	M				
172	**F**	46% dec.	3.6 log dec.	M	M				
176	**F**	29% dec.	M	M	M				
180	**F**	M	M	M	Exceeds limit				
204	**F**	21% dec.	M	M					
225	**F**	22% dec.	M	M	M	M			
227	**F**	M	M	M	Exceeds limit	M			
228	**F**	M	M	M	Exceeds limit	M			
235	**F**	31% dec.	M	M					
245	**F**	26% dec.	M	M	M				
246	**F**	M	M	M	Exceeds limit				
247	**F**	M	M	M	Exceeds limit				
248	**F**	M	M	M	Exceeds limit				
250	**F**				Exceeds limit	M			
254	**F**			M	Exceeds limit	Bean yield 26% of control.			
256	**F**				Exceeds limit	Bean yield 65% of control.			
257	**F**				Exceeds limit	Bean yield 45% of control.			
259	**F**				Exceeds limit	Bean yield 18% of control.			
260	**F**			M	M	Bean yield 30% of control			
261	**F**				Exceeds limit	Bean yield 52% of control.	M	13% of control	M
262	**F**				Exceeds limit	Bean yield 16% of control.			
265	**F**				Exceeds limit	M			
267	**F**				M	Bean yield 67% of control			
270	**F**				M	Bean yield 67% of control			
271	**F**				M	Bean yield 52% of control	M	M	M
285	**F**				M	Bean yield 69% of control			
423	**F**				Exceeds limit				
454	**F**				Exceeds limit				

'M' indicates that a biological property was measured but no significant ($p<0.05$) effect was recorded, or the grain Cd limit was not exceeded.
*A soil failed if wheat grain Cd or Pb concentration exceeded the limit of 0.20 mg/kg fw (0.235 mg/kg dw at 85% dry matter; EC 2001.)

5 Results

5.1 Assessor's report

A copy of the report received from the assessor is reproduced in Appendix III.

5.2 Regime performance

A total of 95 soils were assessed, of which 69 soils failed and 26 soils passed based on the measured and statistically significant ($p<0.05$) biological effects data (Tables 10 and 11).

The Sludge (Use in Agriculture) Regulations (SI, 1989) and the Code of Practice for Agriculture Use of Sewage Sludge (DoE, 1996) made only 53 and 61 correct assessments, respectively, compared with around 70 correct assessments for the EC Working Document on Sludge and EU Risk Assessment regime (Table 11 and Figure 4). Importantly, the Sludge (Use in Agriculture) Regulations (SI, 1989) and the Code of Practice for Agriculture Use of Sewage Sludge (DoE, 1996) were under-protective for 34 and 25 soils, respectively. The Sludge (Use in Agriculture) Regulations were over-protective of eight soils due to cadmium (3), copper (2), nickel (2) and lead (1), but not due to zinc. The Code of Practice for Agriculture Use of Sewage Sludge was over-protective of nine soils, but only in one case was this due to zinc (Table 11).

The EC Working Document on Sludge had a high number (17) of over-protected soils mainly due to cadmium (12), copper (10) and zinc (6) – note that some soils may fail on more than one metal. It was under-protective for only seven soils. Similarly, the EU Risk Assessment had 17 over-protected soils mainly due to cadmium (11) and zinc (4). This may indicate that the limits for cadmium, copper and zinc in these regimes are set too low for some soils. The EU Risk Assessment was under-protective for only six soils.

NB. Because of the way the data from the soils database were selected (to include all instances where soils failed on biological criteria), these results may actually under-estimate the 'over-protectiveness' of the regimes; that is, if more soils that passed based on the biological criteria were to be assessed, then the proportion of over-protected soils is likely to increase.

Table 11. Assessment of regime performance.

Soil No.	Sludge (Use in Agriculture) Regs 1989	Sludge COP 1996 /Compost QP/WMLR/BSI Topsoil	EC 3rd Working Document on Sludge 2000	EU Risk Assessment
4	PF	PF	FF - Zn,Cu	FF - Zn
9	FF - Cu	FF - Cu	FF - Zn,Cu, Cd	FF - Cu
11	FF - Cu	FF - Cu	FF - Zn,Cu	FF - Zn, Cu
13	PP	FP - Zn	FP - Zn,Cu,Cd	FP - Zn, Cd
44	PP	PP	FP - Cd	FP - Cd
50	FP - Cu	FP - Cu	FP - Cu, Cd	FP - Cu, Cd
51	FP - Cu	FP - Cu	FP - Cu, Cd	FP - Cu, Cd
54	PP	PP	FP - Cu, Cd	FP - Cd
55	FP - Cd	FP - Cd	FP - Cu, Cd	FP - Cd
64	PF	PF	FF - Zn,Cu	PF
74	FP - Cd	FP - Cd	FP - Zn, Cu, Cd	FP - Cd
75	FF - Cd	FF - Cd	FF - Zn,Cu,Cd	FF - Cd
78	PF	PF	FF - Zn,Cu	PF
81	PP	PP	PP	PP
104	PP	PP	PP	PP
109	PP	PP	FP - Cu	PP
128	PP	PP	FP - Zn	FP - Zn
133	PP	PP	FP - Cu	FP - Cu
143	PP	PP	PP	PP
145	PP	PP	PP	FP - Cd
150	PP	PP	FP - Zn, Cu	FP - Zn
152	FF - Zn	FF - Zn	FF - Zn, Cu, Cd	FF - Zn
160	FP - Cd	FP - Cd	FP - Cu,Cd	FP - Cd
163	PF	PF	PF	PF
179	PF	PF	FF - Cu, Cd	FF - Cd
195	PF	PF	FF - Cd	FF - Cd
196	PF	PF	FF - Cd	FF - Cd
210	PF	FF - Zn	FF- Zn	FF - Zn
216	PF	PF	FF - Cd	FF - Cd
217	FF - Cd	FF - Cd	FF - Cd	FF - Cd
229	PP	PP	PP	PP
251	PP	PP	PP	PP
255	FF - Zn	FF - Zn	FF - Zn,Cu,Cd	FF - Zn
258	FF - Cu	FF - Zn,Cu	FF - Zn,Cu,Cd	FF - Zn, Cu
263	FF - Cu	FF - Cu	FF - Zn,Cu	FF - Cu
274	PP	PP	PP	PP
278	FF - Cu	FF - Cu	FF - Zn,Cu	FF - Zn, Cu
279	PP	PP	FP - Ni	FP- Ni
280	FP - Ni	FP - Ni	FP - Zn, Ni	FP- Ni
282	PF	PF	FF - Cd	FF - Cd
286	FP - Ni	FP - Ni	FP - Zn,Ni,Cd	FP- Zn, Ni, Cd
287	PF	PF	FF - Cd	FF - Cd
288	PP	PP	PP	PP
291	PP	PP	PP	PP
341	FP - Pb	FP - Pb	FP - Pb	FP - Pb
445	PP	PP	FP - Cd,Pb	FP - Cd
447	FF - Cd, Pb	FF - Cd, Pb	FF - Cd,Pb	FF - Cd, Pb
458	FF - Cd	FF - Cd	FF - Cd	FF - Cd

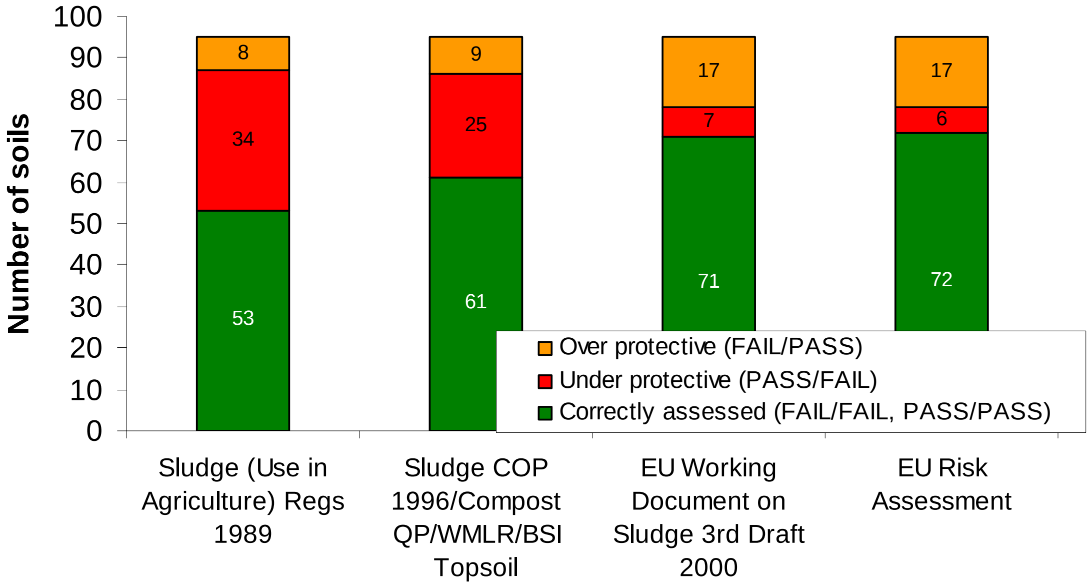
PP	Pass/Pass
FF	Fail/Fail
PF	Pass/Fail
FP	Fail/Pass

Table 11 (cont.). Assessment of regime performance.

Soil No.	Sludge (Use in Agriculture) Regs 1989	Sludge COP 1996 /Compost QP/WMLR/BSI Topsoil	EC 3rd Working Document on Sludge 2000	EU Risk Assessment
5	FF - Zn, Cu	FF - Zn, Cu	FF - Zn, Cu	FF - Zn, Cu
6	FF - Zn	FF - Zn	FF - Zn, Cu	FF - Zn, Cu
7	FF - Zn	FF - Zn	FF - Zn, Cu	FF - Zn, Cu
10	FF - Cu	FF - Cu	FF - Zn, Cu	FF - Zn, Cu
15	FF - Cd	FF - Cd	FF - Zn, Cu, Cd	FF - Zn, Cu, Cd
45	PF	FF - Zn	FF - Zn, Cu, Cd	FF - Zn, Cd
46	FF - Zn	FF - Zn	FF - Zn, Cu, Cd	FF - Zn, Cd
65	FF - Zn	FF - Zn	FF - Zn, Cu, Cd	FF - Zn
66	FF - Zn	FF - Zn	FF - Zn, Cu, Cd	FF - Zn
67	FF - Zn, Cu	FF - Zn, Cu	FF - Zn, Cu, Cd	FF - Zn
87	PF	FF - Zn	FF - Zn, Cu	FF - Zn
95	FF - Cd	FF - Cd	FF - Zn, Cu, Cd	FF - Cd
106	PF	FF - Zn	FF - Zn, Cu	FF - Zn
107	FF - Zn	FF - Zn	FF - Zn, Cu	FF - Zn
129	PF	FF - Zn	FF - Zn	FF - Zn
140	FF - Cd	FF - Cd	FF - Cd	FF - Cd
151	PF	FF - Zn	FF - Zn, Cu	FF - Zn
156	FF - Cu	FF - Cu	FF - Cu	FF - Cu
170	PF	FF - Zn	FF - Zn, Cu	FF - Zn, Cu
171	PF	FF - Zn	FF - Zn, Cu	FF - Zn, Cu
172	FF - Zn	FF - Zn	FF - Zn, Cu	FF - Zn, Cu
176	FF - Cu	FF - Cu	FF - Cu	FF - Cu
180	FF - Cd	FF - Cd	FF - Cu	FF - Cd
204	PF	PF	FF - Cu	FF - Cu
225	PF	PF	FF - Cu	FF - Cu
227	PF	PF	FF - Cd	FF - Cd
228	PF	PF	FF - Cd	FF - Cd
235	PF	PF	FF- Cu	FF - Cu
245	FF - Cu	FF - Cu	FF - Cu	FF - Cu
246	PF	PF	FF - Cd	FF - Cd
247	FF - Cd	FF - Cd	FF - Cd	FF - Cd
248	FF - Cd	FF - Cd	FF - Cd	FF - Cd
250	PF	PF	PF	PF
254	PF	FF - Zn	FF - Zn	FF - Zn
256	PF	PF	FF - Cu	FF - Cu
257	PF	PF	FF - Zn, Cu, Cd	FF - Zn, Cu
259	FF - Zn, Cu	FF - Zn, Cu	FF - Zn, Cu, Cd	FF - Zn, Cu
260	PF	PF	FF - Cu	FF - Cu
261	FF - Cu	FF - Cu	FF - Cu	FF - Cu
262	FF - Cu	FF - Cu	FF - Cu	FF - Cu
265	PF	PF	PF	PF
267	PF	PF	PF	FF - Zn, Ni
270	PF	PF	PF	FF - Ni
271	PF	PF	PF	FF - Ni
285	FF - Cu	FF - Cu	FF - Zn, Cu	FF - Zn, Cu
423	PF	PF	PF	PF
454	FF - Cd	FF - Cd	FF - Cd	FF - Cd

PP	Pass/Pass
FF	Fail/Fail
PF	Pass/Fail
FP	Fail/Pass

Figure 4. Number of soils for which each regime was over, under or sufficiently protective.



Soils that 'failed' based on one or more of the biological criteria were analysed in more detail. There were fewer under-protected soils (PASS/FAIL) using the Code of Practice for Agricultural Use of Sewage Sludge compared with the Sludge Regulations (from 23 to 14, Figure 5) due to the introduction of lower maximum permissible zinc concentration (200 mg/kg for soils of pH<7, compared with 300 mg/kg for soils of pH 6-7 and 250 mg/kg for soils of pH 5.5-6.0; see Tables 1 and 2). Figure 5 also shows that the lower limits for zinc and copper (150 mg zinc/kg and 50 mg copper/kg for soils of pH 6-7) suggested in the EC Working Document on Sludge (Table 3) would enable nine additional soils, which 'failed' the biological criteria based on significant reductions in microbial biomass, rhizobia numbers or crop yield, to be correctly assessed compared with the Code of Practice for Agricultural Use of Sewage Sludge. Moreover, through consideration of (bio)availability for copper, nickel and zinc, the EU Risk Assessment approach was able to predict 46 of the 50 selected soils correctly when cadmium in grain was not considered (Figure 5). Of the whole dataset (95 soils), only six soils were under-protected using these limit values (Figure 4).

The EU Risk Assessment approach was also able to correctly assess soils 267, 270 and 271 as failing on nickel (soil nickel concentrations of 19, 29 and 34 mg/kg, respectively, with significant reductions in crop yield), suggesting that the limit of 50 mg nickel/kg (pH 6 <7) proposed in the EC 3rd Working Document on sludge may not be sufficiently protective of crop yield for some soils. Note that not all the soils in the database had measured soil nickel concentrations, and those where nickel was measured tended to be sandy soils with low background concentrations (<15 mg nickel/kg compared with the average for England and Wales of 25 mg/kg – McGrath and Loveland, 1992). Therefore, generalisations from this small subset of soils, for which nickel was a priority, need to be treated with caution.

There were 27 soils which failed the biological assessment because wheat grain cadmium concentrations exceeded the limit of 0.20 mg/kg fw. The Sludge Regulations and Code of Practice for Agricultural Use of Sewage Sludge are based on a maximum permissible soil cadmium concentration of 3 mg/kg regardless of soil pH (Tables 1 and 2). However, Figure 6 shows that this limit value did not sufficiently protect 14 and 15 of the soils, respectively (that is, the 3 mg/kg limit was not low enough to protect the quality of wheat grain). The EC Working Document on Sludge (2000) proposed a limit of 0.5–1.5 mg cadmium/kg depending on soil pH (see Table 3), and Figure 6 shows that this was sufficiently protective for all but three of the soils. However, the EC Working Document on Sludge was over-protective for cadmium in 10 cases (Table 11). The EU Risk Assessment approach had a similar performance for cadmium, though it should be remembered that cadmium was not one of the 'prompt values' (along with lead) for which a full-(bio)availability-based approach was available. Note: the EU Risk Assessment was over-protective for cadmium in 11 cases (see above), which seems to imply that while the 3 mg/kg limit in the Sludge Regulation and Code of Practice may be under-protective, the EC Working Document on Sludge and EU Risk Assessment limits may be over-protective for some soils.

Figure 5. Soils which failed on biological criteria ($p<0.05$) other than where wheat grain cadmium exceeded 0.20 mg/kg fw, showing which regimes were under or sufficiently protective.

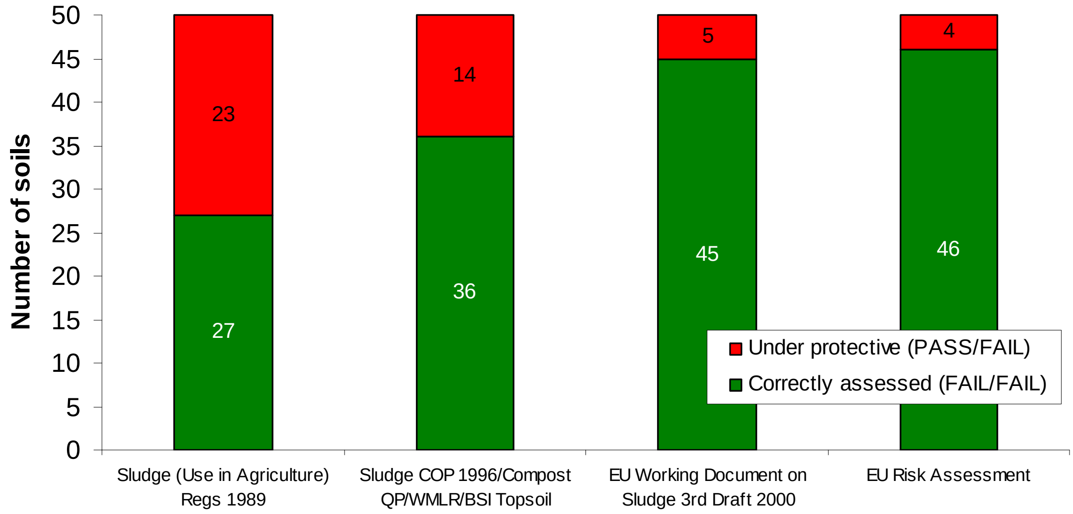
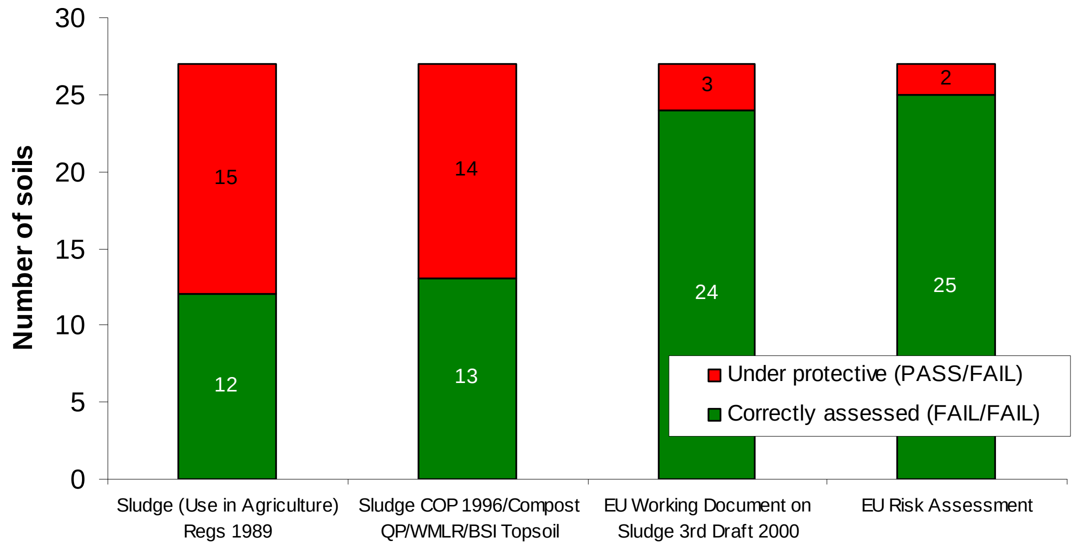


Figure 6. Soils where wheat grain cadmium exceeded 0.20 mg/kg fw, showing which regimes were under or sufficiently protective.



There were a few soils that failed on one or more of the biological criteria, but which were not correctly assessed by any of the regimes. Soil 163 failed because of a significant reduction in the size of the soil microbial biomass, although soil zinc and copper concentrations were only 87 and 23 mg/kg, respectively. Soils 250 and 423 exceeded the wheat grain cadmium concentration of 0.2 mg/kg fw, although soil cadmium concentrations were <0.3 mg/kg. These instances may be due to analytical or sampling errors or other factors (for example, other contaminants in the applied organic material), or simply statistical chance (for example, where $p<0.05$ there is a 1 in 20 chance that the measured effect is simply due to random probability).

5.3 Regime usability and interpretation

There were a number of issues highlighted in the assessors report (Appendix III) relating to the way in which the different regimes were used and the results interpreted.

5.3.1 Ease of use and transparency

The simple 'look-up' table approach employed by many of the regimes is transparent, straightforward to use and requires a minimum amount of data (soil metal concentration and pH only), although often the derivation of the values used in such tables is by no means clear. This project has demonstrated that a 'look-up' table approach (for example, the EC Working Document on Sludge) can be as successful in protecting soils as the more sophisticated approach employed by the EU Risk Assessment. However, whilst both approaches appear to perform equally well, the scientific basis of the values in the EC Working Document is not transparent and has not been documented, unlike that of the EU Risk Assessments.

The Excel spreadsheet developed by EURAS and the Environment Agency for using the EU Risk Assessment methodology, whilst requiring more soils data (for example, soil texture, organic matter content) was also simple to use. The experimental data and approach adopted to derive the environmental risk assessment have been well documented (Netherlands 2006; ECI 2007; Denmark 2007; LDAI 2007; Belgium 2007), although this is not immediately apparent to the user of the spreadsheet.

5.3.2 Analytical technique

There are a number of methods by which soil 'total' metal content can be measured (such as digestion in aqua regia or nitric acid, metal analysis using AAS or ICP), with different methods giving different results. Most regimes specify (or recommend) an analytical method, although these are not consistent across regimes, even where the same limit values are used. For example, the Code of Practice for Agricultural Use of Sewage Sludge recommends a hydrochloric-nitric acid digestion (SCA, 1992), whereas the BSI Topsoil Standard states that a microwave nitric acid extraction should be used for zinc, copper and nickel determination (Lambkin *et al*., 2004). Clearly, the more recent BSI Topsoil Standard regime has been able to recommend more up-to-date techniques proposed for harmonised use across the EU, but it is not clear how results derived using this technique compare with those using the older methods recommended in current UK sludge legislation.

Another issue is when the soil is very close to the limit value, such that within the precision of the sampling technique or analytical method the soil could pass or fail a regime. For example, a soil may have been analysed at 200 mg zinc/kg, which is the 'prompt value' for a regime, but the precision of the analytical method is ± 2 mg/kg – does the soil pass or fail that regime?

5.3.3 Soil pH

Soil pH is a key factor influencing metal bioavailability in soils, a fact reflected in the pH 'banding' approach to limit values that is commonly adopted. Some regimes (such as the EC Working Document on Sludge, 2000; Table 3) set maximum permissible concentrations based on soil pH bands for all six metals (zinc, copper, nickel, cadmium, lead and mercury) while UK approaches (SI, 1989; DoE, 1996; Tables 1 and 2) only consider pH as a factor controlling for zinc, copper and nickel bioavailability.

Many of the regimes do not extend below 5.0, hence a soil with a pH <5.0 would not be considered suitable for use in this context. Indeed, the current UK legislation and the EC Working Document on Sludge specifically state that sludge may not be spread to land where the pH (in water) is <5.0 (SI, 1989; DoE, 1996; EC, 2000).

5.3.4 Soil texture

A consistent approach is needed prior to implementation of a system that utilises soil texture to assess metal limits (such as the EU Risk Assessment and UK SSVs) as there are a number of different textural classification systems used both within the UK and EU.

5.3.5 Background soil metal concentrations

The initial soil metal status (prior to application of any organic material) can be an important guide to the potential of a soil to accept further metal inputs. This is not currently included in UK regimes (SI, 1989; DoE, 1996; BSI, 2007) or the EC Working Document on Sludge (EC, 2000), however it may be worth considering how it could be included in such approaches provided the schemes do not become overly complex.

5.3.6 Rounding and threshold values

There are questions to be asked when soil pH is close to the threshold (for example, 6.03 for Soil 26). Should this value be rounded down to one decimal place, which could potentially push the soil into a lower pH band than if no rounding was permitted? This could make the difference between a soil passing or failing a regime. This is not clearly specified in any of the regimes, although it is implicit that pH values to one decimal place are sufficient.

Similar issues arise over measurements of soil metal concentrations, where it is implicit that measurements to the nearest integer are sufficient. Nevertheless, there is perhaps a need for more clarity regarding the position to be taken on rounding of values, and also on what happens when a soil is exactly equal to the threshold value.

A further issue relates to the desirability of exceeding the threshold values under a given regime. If a soil is just below a threshold value, such that the organic material additions are technically permitted, is it acceptable to apply a material at a rate which could subsequently take the soil over the threshold?

5.3.7 Missing values

In the soils database there was no data provided for mercury, despite critical values being specified in most of the regimes, and lead and nickel data were only available for a small numbers of the soils. In practice, the regimes will require all the specified metals to be measured before an assessment of a soil can be made.

5.3.8 Limit value and tiered approaches

One objective of this study was to determine the balance between environmental protection and the occurrence of situations where a regime was over- or under-protective of the soil. Most regimes operate using a simple ‘limit value’ approach – if a soil was below the limit value it passed, if not it failed, with no opportunity for a more detailed assessment. However, with the EU Risk Assessment (and proposed SSVs) the methodology was used within a tiered framework. Thus, a soil may ‘fail’ the first stage of testing and the regime could be considered to be over-protective. However, this prompts another test, which the soil may ‘pass’ and so resolve the issue of over-protection.

6 Summary and Conclusions

6.1 Summary

This project began by identifying all the regimes (legislative requirements and guidance documents) in current use or proposed for use in the UK to control metal inputs to soils from organic material additions. The different soil metal limits and protection goals for each regime are summarised in Section 4.2 of this report.

A comprehensive database of more than 500 field soils that had received organic material additions (such as sewage sludge, farm manures, compost, paper crumble) was complied from a number of experiments at sites throughout Britain, on different soil types and land uses. Each database entry consisted of a suite of soil data (including texture, pH, organic matter content and metal concentrations) together with one or more biological measurements (for example, soil microbial biomass, rhizobia numbers, respiration rate, wheat grain cadmium content, earthworm numbers). The biological measurements were used as an indicator of whether there had been a decrease in soil quality due to metals added in the organic materials.

A methodology was developed to allow the performance of the different regimes in protecting soil quality to be compared using the soils database, and to highlight instances where the regimes may be under-, over- or sufficiently protective of soil quality.

6.2 Conclusions

- This project was the first time a number of limit values for metals in soils specified in regimes currently used or proposed for use in the UK were validated in terms of whether they are predictive of risk conditions, as judged by secondary data on soil biological process.

- The methodology developed uses a statistically significant ($p<0.05$) change to a biological measurement (compared with a control) to indicate that a soil has 'failed'. However, this may not necessarily indicate that there was a detrimental effect on soil quality and function. For example, there may have been a significant reduction in biomass size, but only by 10 per cent of the value measured on the control soil. At present, there is no evidence to determine whether a 10 per cent reduction in biomass is in fact 'harmful'. Further work is needed to establish the magnitude of change in a biological parameter that should be considered unacceptable in this context.

6.2.1 The Sludge (Use in Agriculture) Regulations (1989) and the Code of Practice for Agricultural Use of Sewage Sludge (1996)

- The Sludge (Use in Agriculture) Regulations and the Code of Practice for Agricultural Use of Sewage Sludge (the existing sludge limits used in the UK) were found to be under-protective for 34 and 25 of the 95 soils tested, respectively. This suggests that the existing limit values (Tables 1 and 2) used not only in these regimes, but which also ‘read across’ into other legislation and guidelines, may not be sufficiently protective of soil quality.

- There were fewer under-protected soils using the Code of Practice for Agricultural Use of Sewage Sludge than the Sludge Regulations due to the introduction of lower maximum permissible soil zinc concentrations (200 mg/kg for soils of pH<7, compared with 300 mg/kg for soils of pH 6-7 and 250 mg/kg for soils of pH 5.5-6.0 in the Sludge Regulations).

- Only eight or nine of the 95 soils were over-protected by these regimes. Furthermore, under the Code of Practice for Agricultural Use of Sewage Sludge, only one soil was over-protected on the basis of zinc.

6.2.2 BSI Topsoil

- In practice, the metal limits for soils compliant with the BSI Topsoil Standard are the same as those specified in the Code of Practice for Agricultural Use of Sewage Sludge, despite the different protection goals of the two regimes.

6.2.3 EC ‘Working Document on Sludge’ 3rd Draft (2000)

- The implementation of lower limits for zinc, copper and cadmium (150 mg zinc/kg, 50 mg copper/kg and 1 mg cadmium/kg for soils of pH 6-7) proposed in the EC Working Document on Sludge would reduce the number of under-protected soils (seven of the 95 soils) compared with current UK legislation.

- This regime had a high number (17) of over-protected soils, mainly due to cadmium, copper and zinc, which may indicate that the limits for these metals are set too low for some soils.

6.2.4 EU Risk Assessment

- The EU Risk Assessment ‘prompt values’, which considered site-specific soil factors and bioavailability for copper, nickel and zinc, correctly assessed 72 of the 95 soils tested and were under-protective of only six soils.

- This regime over-protected 17 soils, mainly due to cadmium and zinc. This may indicate that the limits for these metals are set too low for some soils, but within the tiered framework in which they are to be used, this may not be a significant issue.

- In general, the ‘prompt values’ performed well in predicting potential risks, but were also over-protective in some situations. While the EU Risk Assessment ‘prompt values’ effectively calculate a site-specific limit value (considering soil specific physico-chemical characteristics), simple ‘look-up’ tables, similar to those currently in use in the Code of Practice for Agricultural Use of Sewage Sludge, could be constructed as currently used in Australia and other countries (cf. http://www.clw.csiro.au/research/biogeochemistry/assessment/biosolids /documents/NBRPFinalSeminar4-CdFramework.pdf).

6.2.5 Cadmium

- Results from this ‘road testing’ process indicate that there were a number of soils which ‘passed’ soil cadmium limit values specified in the Code of Practice for Agriculture Use of Sludge (DoE, 1996), but ‘failed’ the validation test because wheat grain cadmium concentrations were greater than the EU maximum permissible concentration (MPC) of 0.2 mg/kg (fresh weight); that is, the regime was under-protective. This assessment is supported by recently published work which showed that the current UK soil total cadmium limit of 3 mg/kg was not sufficiently protective against producing grain above the EU grain cadmium MPC unless the soil pH was >6.8 (Chaudri *et al*., 2007). Furthermore, recent research in Australia has also demonstrated the need to consider soil factors (such as pH) in assessing cadmium ecological and human health risks (McLaughlin *et al.,* 2006).

- If the suggested limit of 1 mg cadmium/kg for soils of pH 6<7 (EU, 2000) was introduced or if the EU Risk Assessment value of 1.1 mg cadmium/kg was used, the number of under-protected soils would be considerably reduced. However, these values also lead to a significant number of over-protections, suggesting the need for prompt values based on soil properties.

- Soil pH has long been known to be a key factor influencing the availability of many metals in soils. Some regimes (such as the EC Working Document on Sludge) set maximum permissible concentrations based on soil pH bands for six metals (zinc, copper, nickel, cadmium, lead and mercury) whilst UK approaches (SI, 1989; DoE, 1996) only consider pH as a factor controlling zinc, copper and nickel bioavailability. Given the weight of research evidence and the findings from this project of reduced numbers of under-protected soils where regimes take soil pH into account, we recommend that future changes to UK legislation should embody a pH-based approach for setting soil cadmium limits.

- It is important to be aware that the cadmium limit in the existing UK sludge legislation was intended to ensure that animal or human health is not put at risk through the food chain. In contrast, the EU Risk Assessment values were designed to protect the soil ecosystem. This explains why the EU Risk Assessment has a lower cadmium limit value and the apparent over-protectiveness of the regime when assessed against the wheat grain cadmium limit concentration that is in place to protect the food chain. This highlights the importance of a correct understanding and interpretation of the protection goals of the different regimes.

6.2.6 Overall conclusion

- There is clearly *a balance to be struck* between environmental protection and regulation and the sustainable recycling of organic material to land. The protection goals of each of the regulatory regimes tested were not always clear, and wording in the regulations was not always readily interpretable without scientific data. However, their goals can be interpreted broadly in terms of soil protection and terrestrial ecological health. What is clear from this project is that both the science and understanding of metal behaviour in soils has moved on significantly in the last decade and relatively accurate predictions of metal risks are now possible. Furthermore, it is apparent that the existing limit values for metals in soils, so widely used for the *de facto* assessment of environmental metal risks, may not be wholly protective.

- It is likely that some soils within a national monitoring scheme may have relatively low metal concentrations, which would be below the ‘prompt values’ specified in all the regimes tested in this project, including the EU Risk Assessment/SSVs that were proposed for this purpose. Nevertheless, an increase in metal concentrations in such soils (for example as a result of organic material additions) could be indicative of a long-term threat to soil quality. Hence, within a national monitoring scheme, it may be more appropriate to look at using ‘prompt values’ in combination with an assessment of changes in soil metal concentrations over time above a specified value. Also, in order to provide an early warning that ‘prompt values’ were being approached, we could set a 75 per cent of the ‘prompt value’ ‘early warning’ limit. For example, if the soil zinc ‘prompt value’ was 149 mg/kg, then the ‘early warning’ value would become 112 mg/kg, and if a soil exceeded this value it would trigger the next tier of investigation, depending on at what point metals are to be considered in the monitoring scheme. If metal levels are quantified at an early stage of the scheme (that is, at tier one), limited information will be available for each site and an early warning system is advisable. However, at a higher tier (that is, tier 2 or above), information that triggered further investigation and metal analyses will be available and use of the prompt values is advised, in line with the Contaminated Land regime.

- In addition, in terms of the national dataset as a whole, it would be pertinent to assess if there has been a change in the number of soils exceeding the ‘early warning’ and ‘prompt values’ as well as changes over time from the baseline measurement. For example, if in the baseline year five per cent of soils in the monitoring scheme fail the 112 mg/kg ‘early warning’ value for zinc, and if at the next sampling date this had increased to 10 per cent, this would trigger further site specific investigation.

7 Recommendations for further work

- The outputs from this project highlight the need to re-assess current limit values for some metals in relation to the way they are used and interpreted, and stress the advantage of considering bioavailability. For cadmium in particular, considerable data exist stressing the need to derive a limit value that is ‘fit for purpose’ and addresses appropriate end points for human health and the environment. ‘Look up’ tables based on pH (and texture) have been derived in other countries, and would be relatively straightforward to implement for UK soils.

- The data used in this project represent only a small ‘snap shot’ of the total information against which a complete assessment of the individual regimes could be undertaken. This is because, due to the nature of the research projects from which they were taken, a complete suite of biological data was not available for all (or indeed any) of the soils. For example, soil microbial biomass and rhizobia numbers were not measured in soils where the aim of the study was to investigate grain cadmium and lead concentrations. More comprehensive data would be required to assess whether a regime was truly achieving its protection goals, particularly where a regime specifies broad soil health/quality/function considerations.

- Data from the Long-term Sludge Experiments have indicated that zinc applied in sludge cake has a different impact on soil microbial processes to that applied in metal amended liquid sludge or a metal salt, whereas the effect of copper on soil biota appears to be independent of the metal source (that is, due to copper *per se*). Research is needed to understand the processes controlling the behaviour of metals entering soils from other sources of organic materials (that is, livestock manures - in particular pig and poultry manures, and composts), which may contain elevated concentrations and/or result in elevated loading rates of zinc and copper.

- The Long-term Sludge Experiments have provided invaluable field data for use in assessing the performance of the different regimes. In future, consideration could be given to using additional biological measurements (such as earthworm counts, pea/bean rhizobia numbers) and newer assay techniques (such as phospholipid fatty acid profiles) to further assess the effects of zinc and copper additions on the soil ecosystem.

- The methodology used for this validation may be readily applicable to other limit values for other environmental compartments, such as waters and sediments.

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Appendix I Generic Guidance for the Assessment of Soils - Metals

1. Introduction

This note briefly outlines the background behind a number of regulations and guidance notes that use numerical values against which soil chemical characteristics are compared to facilitate decisions. Each section gives the regime protection goals and briefly describes the processes by which soils data are manipulated in order to allow the decision to be taken.

The numerical values or standards (as described by RCEP, 1998) are used in two distinct ways in the regulatory regimes concerning soils. Largely this use is 'retrospectively', that is, the standard is looking at material already present within the soil, or to a lesser extent 'prospectively' where a standard is used to issue a permit – assessing an effective 'head room' for a particular substance.

The regimes listed below all rely on site-specific soil assessment against a numerical standard – considering, to a greater or lesser extent, soil physico-chemical conditions.

1.1 Methodology and Process

The following sections of this guidance outline the protection goals of the regimes under consideration. Further, an indication is given as to the aims of the standards in terms of protection goals and also how the numerical values are supposed to be interpreted within the framework of the regime.

It can be assumed that for each soil scenario the soil was sampled in accordance with the specific requirements of that regime. Standards are given along with the conditions set out in the regime in tables (that is, pH). The nomenclature (ambiguity?) used in that regime in regard to the soil standard is reflected in the background section and in the respective tables.

Instruction boxes are given beneath each regime description to explain how the assessment using the soil specified in the scenario is to be used. These instructions are informed by the requirements of the regime; only information required by the regime is to be used in making assessments.

2. Regulations and Regimes

2. 1. Sewage Sludge Regulations

This regulation is directed to the protection of the environment, in particular the soil, when sewage sludge is used in agriculture. Specifically, the directive states that sludge should be used in such a way 'as to prevent harmful effects on soil, vegetation, animals and man'. The following should be observed when using sludge: the sludge shall be used in such a way that account is taken of the nutrient needs of the plants and that the quality of the soil and of the surface and groundwater is not impaired.

Table 2.1 gives the limit values for metals in soils amended with sludge from the Sludge Regulations (1989). These values are related to the soil pH and total soil metal values are to be compared to these values at the respective pH of the amended soil (or the soil prior to amendment).

Table 2.1. Limits for total metal concentrations in sludge amended soils (mg/kg dry weight) Sludge (Use in Agriculture) Regulations, 1989.

	Soil pH			
	5.0<5.5	**5.5<6.0**	**6.0<7.0**	**>7.0**
Zn	200	250	300	450
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

Table 2.2 gives the maximum permissible concentrations of metals in soil amended with sludge from the Sewage Sludge Code of Practice (1996). The key difference with these values is in regard to the value of zinc, which was reduced as a 'precautionary measure' in accordance with the recommendations of an Independent Scientific Committee review of *soil fertility* aspects of metals (Smith, 1996).

Table 2.2. Maximum permissible concentrations of metals in soils (mg/kg dry weight) after application of sewage sludge (DoE, 1996).

		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
		For pH 5.0 and above		
Cd			3	
Pb			300	
Hg			1	

* These are advisable limits.

Table 2.3 gives the limit values set under the EC 'Working Document on Sludge' 3rd Draft (2000). The use of sewage sludge in this regulation is to be undertaken in such a way as to minimise the risk of negative effects on:

- Human, animal and plant health.
- The quality of groundwater and/or surface water.
- Long-term quality of the soil.
- The biodiversity of the microorganisms living in the soil.

Table 2.3 Limit values for concentrations of metals in soils to receive sewage sludge or having received sewage sludge (mg/kg dry weight).

	Soil pH		
	5.0<6.0	**6<7.0**	**>7.0**
Zn	60	150	200
Cu	20	50	100
Ni	15	50	70
Cd	0.5	1	1.5
Pb	70	70	100
Hg	0.1	0.5	1

Instruction

Under this regime the values given in the tables should not be exceeded if the protection goals are to be achieved in soils having received sewage sludge or set to receive further applications of sludge. Published guidance suggests that additional physico-chemical properties that would be collected along side the metals data would include: soil pH, available nitrogen, phosphorous and potassium and SOC.

Using the information given in this section combined with the chemical properties in the soil scenario database determines whether, under these regimes, the protection goals as given, are currently being met.

2.2. Compost Quality Protocol

This Quality Protocol has three main purposes:

- To clarify the point at which waste regulatory controls are no longer required.
- To provide users with confidence that the compost they purchase conforms with an approved standard.
- To protect the environment (including soil) and human health by describing acceptable best practice for the use of quality compost on land used for agriculture or soil-grown horticulture.

Quality compost must not be used in such a way as to adversely affect human health or the environment. Under the Protocol, quality compost can be used in agriculture and soil-grown horticulture as a soil 'improver or mulch' *provided* it is used in such a way that does not pose a risk to the environment and its use does not compromise the future sustainable use of the soil to which it is applied.

The compost producer or user must be able to demonstrate that they have taken full account of any environmental impact resulting from its use. Metal analyses of the soil is required prior to the first application of compost and again when the predicted concentrations approach 75 per cent of the limit values set out in Table 2.4.

Table 2.4. Maximum permissible concentrations of metals in soils (mg/kg dry weight) after application of sewage sludge (DoE, 1996).

		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
		For pH 5.0 and above		
Cd			3	
Pb			300	
Hg			1	

* These are advisable limits.

Instruction

Directly compare the values in Table 2.4 with the metal levels in the soils and indicate which would fail to meet the requirements for compost (or further compost) application. You may utilise pH to indicate which values in table 2.4 are the most appropriate to use in making your assessment.

Further, using the information given in this section combined with the chemical properties in the soil scenario database (that are required for this regime), determine whether the protection goals are met and if further additions of the respective material are to be made to each soil.

2.3. Waste Management Licensing Regulations.

Waste to land recovery activities are exempted under the Waste Management Licensing Regulations (1994). Relevant waste to land exemptions must be of benefit to agriculture or ecological improvement (Part 2 of Table 2AA). Definitions of these two terms are not given in the legislation, but statutory guidance suggests that it should be ensured that the waste going to land serves a useful purpose by replacing other substances that otherwise would have been used for that purpose (that is, conserving natural resources). Further, under the regulation all activity must be carried out in a manner that will not harm the environment – 'without risk to water, air, soil and plants and animals'. The use of the term 'without risk' stipulates an absolute level of protection. The exemptions are needed for materials such as composts, sediment dredgings or paper pulps to be recycled to land.

The Environment Agency has issued internal guidance providing advice on the technical assessment of 'agricultural benefit' and 'ecological improvement' in reference to characterisation of the waste and also the receiving land (Environment Agency, 2006). There is significant latitude in the guidance and reference is made throughout the document to the necessary use of 'expert judgement'.

Table 2.5. Maximum permissible concentrations of metals in soils (mg/kg dry weight) after application of sewage sludge (MAFF, 1998).

		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
		For pH 5.0 and above		
Cd			3	
Pb			300	
Hg			1	

* These are advisable limits.

The application of the waste must not cause the concentration of any of the metals listed in Table 2.5 to exceed the limits specified in soil. These limits are the same as in Table 2.2, but have been chosen as being relevant because 'their purpose is to protect the food chain'.

Instruction

Under the internal guidance from the Environment Agency, prior to receiving an initial application (or a further application) an assessment of the concentrations of metals in the soil must be made and compared with the values in Table 2.5. Further, there is a requirement for an assessment of the physico-chemical properties of the soil to ensure its suitability. This assessment, as a minimum, would include pH, soil texture, phosphorous, potassium, magnesium (available) at the site.

Using the information given in this section combined with the chemical properties in the soil scenario database determines whether, under this regime, the protection goals are met if further additions of the respective material are to be made to each soil.

2.4. BSI Topsoil

The British Standard for topsoil outlines the requirements for soils that are moved, traded or manufactured. It gives soil standards to ensure that the topsoil quality specification is met. Topsoil is defined in the specification as being natural or manufactured soil in which ‘plants can grow healthily’ and contaminants as substances which ‘may inhibit soil function or cause a risk to animals, humans or the environment. The specification for multipurpose topsoil stipulates that it should be suited for most situations and is capable of supporting grass, trees, shrubs and other plantings. In regard to the presence of contaminants within the topsoil, two categories are given in order to fulfil the characteristics of a multipurpose topsoil. The two categories are ‘chemical contaminants (human health and the environment)’ for which no numerical values are given, but reference is made to ensure suitability for purpose and appropriate conservative assumptions, and secondly ‘phytotoxic contaminants’. This second category is relevant to copper, nickel and zinc and the numerical values are given in Table 2.6.

Table 2.6. Total metal concentrations (mg/kg) not to be exceeded if a topsoil is to be specified as multipurpose under BS3882:2007.

		pH	
	5.5-6.0	**6.0-7.0**	**>7.0**
Zn	<200	<200	<300
Cu	<100	<135	<200
Ni	<60	<75	<110

Instruction

Declaration of compliance to the topsoil standard is undertaken using a pro forma in direct comparison of analytical results of the soil with those present in Table 2.6 at the appropriate pH band.

Using the information given in this section combined with the chemical properties in the soil scenario database determines whether, under this regime, the protection goals are met in achieving the multipurpose top soil specification.

2.5. EU Risk Assessment Value and the UK Soil Screening Values (SSVs).

These values are effectively the same, although the protection goals are not. The values are currently being recommended for use in the UK as screening values in tiered approaches in both the Contaminated Land regime (under Part IIa of the Environment Protection Act 1990) and 'trigger values' in assessing UK Soil Quality. The values are taken from work being undertaken at the auspices of the Existing Substances Regulations (Directive 98/8/EC) programme. The values being recommended are predicted no-effect concentrations (PNECs) and are based on soil ecotoxicological data.

Section 57 of Part 2A of the Environmental Protection Act 1990 (Crown Copyright, 2000) introduced a statutory regime for the identification, assessment and remediation of contaminated land in England and Wales. A tiered approach has been developed for the assessment of ecological receptors at such sites and consists of early screening tiers designed to confirm the 'potential' for harm. At tier one are the soil screening values. For the purposes of this regime harm is 'an irreversible adverse change or some other substantial adverse change' in the 'functioning of an ecosystem' or 'species of special interest'. This is then described in Environment Agency guidance to local authorities and stakeholders in a way that is usable in quantitative risk assessments – as 'adverse change'. This 'adverse change' is change in the growth, reproduction or mortality that endangers the 'functioning of the ecosystem' or 'any species of special interest', or the 'favourable conservation status'. The soil screening values are therefore used to support a decision in respect of these protection goals. It should be stressed that the situations in which these are likely to be used are potentially few, for example where a contaminated site is located next to a Site of Special Scientific Interest or Special Area of Conservation (SAC).

The EU Risk Assessments considers the 'total' concentration of metal in the soil in the field and then applies a number of refinements to that measured concentration to allow for a more realistic comparison with the standard derived from ecotoxicological data. Such data is often produced in laboratory conditions under which metal availability is maximised, a situation unlikely to occur in the field.

The following steps provide an outline of the processes at each stage. If the measured concentration in the field (Predicted Environmental Concentration or PEC) is greater than the standard (Predicted No Effect Concentration or PNEC), one moves to the next stage and further refinement. All of the refinements (and the values on which they are based) are taken from the respective metal risk assessment documents (The Netherlands, 2006; Cu-RAR, 2007)(see accompanying Excel spreadsheet).

Step 1: A direct comparison of the PEC (the measured concentration in the field) at the site with the SSV or PNEC. If the PEC divided by the PNEC is greater than one, then one moves to the next level of refinement.

Step 2: This step takes account of the background concentration of metal in the soil. This background has been derived from the NSI Database and represents a soil of low-level anthropogenic input. A full description on how these texturally based values for metal backgrounds were derived is given in Zhao *et al.* (2007). The relationship between soil textural class and metal concentration is a highly significant one, and introduces greater site specificity and realism into the assessment. If the PEC divided by the PNEC is greater than one, then one moves to the next level of refinement.

Step 3: This refinement accounts for the difference in metal availability in laboratories as compared to the field. Experimentally-based empirical factors are used to correct the field concentration to an effective exposure concentration. Again, if the PEC/PNEC ratio is greater than one, a move to step 4 is required.

Step 4: This step utilises a developed understanding of the soil characteristics that influence the ecotoxicology of a particular metal. This refinement is based on a number of soil physico-chemical parameters depending upon the metal.

At each step of the refinement, the PEC is compared against the PNEC. If levels of a contaminant fall below the PNEC then the site exits the regime. If by the end of the above sequence the level of contamination still exceeds the PNEC and no further refinements are possible, then the risk assessment moves to a more detailed analysis outside the remit of this guidance. An in depth discussion of the experimental data sitting behind these refinements is available in the risk assessment documents (Refs).

Under the auspices of the UK Soil Indicators Consortium, a number of soil quality indicators and related 'trigger values' were selected to assess soil quality against a range of soil related functions. Soil Quality in this context can be defined as: the capacity of a specific soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health habitation. Trigger values can be considered as values or ranges of values above or below which a level of change is understood to be critical in terms of the soil's fitness for a specific use.

The indicators include metals and the values chosen for the 'triggers' and the methodology for their use and refinement are the same as for contaminated land given above. Further, the indicators and 'triggers' used to take a decision on soil quality are also within a risk-based framework. Exceedance of a 'trigger' for a particular metal indicator would prompt the collection of further data and information and possibly the movement to the second level in the framework beyond the remit of this guidance (but we would consider this to exceed the standard and so fail at this stage). The assessments undertaken in regard to both soil quality and contaminated land are retrospective, judgements are being made on what is already present in the soil or what condition the soil is in. The use of these PNECs in both cases is as early screens in a larger risk-based framework.

Instruction

Predicted No Effect Concentrations or soil screening values are used in order to determine whether further information is required to assess the potential for harm to ecological receptors at a specific site. They are used by comparing the total metal concentrations in the site soil with the values given in the spreadsheet. Additional physico-chemical information collected under this regime would be pH, textural class and SOC (or LOI). Some of this information is needed in the spreadsheet to make site-specific corrections. If the PEC/PNEC ratio is greater than one, and all the possible refinements have been undertaken, then the site/soil would move to another level within the regime specific framework (that is, it fails at this level).

Using the information given in this section combined with the chemical properties in the soil scenario database determines whether, under these regimes, the respective protection goals are met for each soil.

For the assessment of soil quality in regard to metals, the same process is followed as for the use, and assessment of the soil metal concentrations against the PNECs for contaminated land. However, the protection goals may be considered to be different.

3. Results and Reporting

The summary report will be in two sections, the first is the summary table for each of the 50 soils and respective regimes that you may wish to do first. The second section is the narrative addressing the reasoning behind decisions made in the summary table. The aim of the report is to give the results of the assessments and to give a judgement as to whether the protection goals for each of the respective regimes have been met in line with the soil standards used.

The Report on Metals

Follow the instruction box with each regime and perform the assessment as outlined. Deliver the specific answer and indicate why you have drawn that conclusion.

However, if you feel that there is ambiguity in the decision-making process or guidance, outline where and why this may be.

Critically assess the value of the standards and process outlined for that regime in terms of achieving the respective protection goals. In this section it may be helpful to cover issues such as:

- Are the standards effective in achieving the protection goals for the regime?
- Is this process practical to follow and understand?
- How much expert judgement is needed in making the decision?
- How much time did each regime require to perform the assessment on the soils?
- What would make the processes clearer, more understandable or more robust?

4. Clarification and iteration

There may be circumstances in which you feel that it is inappropriate to make a judgement and that additional contextual or soil data would help make that decision. A request for this information is to be done via email to: Fiona.Nicholson@adas.co.uk

Clarification may also be sought by the project team on decisions and judgements made in your report. This will also be made by email, but followed up by a telephone call.

5. References

Cu VRA (2007) European Union Risk Assessment Report. Copper, copper(ii)sulphate pentahydrate, copper(i)oxide, copper(ii)oxide, dicopper chloride trihydroxide. Voluntary risk assessment, Chapter 3, draft February 2007. European Copper Institute.

MAFF (1998) The Soil Code: Code of Good Agricultural Practice for the Protection of Soil. MAFF Publications, London.

RCEP (1998) Royal Commission on Environmental Pollution, 21st Report 'Setting Environmental Standards'. HMSO, London, UK.

The Netherlands (2006) Risk Assessment Report: Zinc metal. Final draft of December 2006 (R073_0412_env).

F. J. Zhao, McGrath, S. P. and Merrington, G. (2007) Estimates of ambient background concentrations of trace metals in soils for risk assessment. Environmental Pollution, In Press.

Appendix II Detailed Guidance Note

Purpose:

The purpose of this spreadsheet is to provide an assessment of the potential ecotoxicological risk from cadmium, copper, nickel, lead and zinc for a soil at a specific site. It represents a 'first step' in a broader ecological risk assessment, and should therefore not be considered as an isolated pass/fail criterion.

The spreadsheet represents an attempt to bring together the latest scientific understanding in regard to metals behaviour in soil in a format that is useable by regulators and those being regulated. There is a fundamental acknowledgment behind this process that risks posed by metals are poorly assessed by singular consideration of the 'total' soil metal concentration, and that soil and soil organism factors will influence potential toxicity.

There are a number of steps outlined in the sheet which correct exposure (measured concentrations at the site) and effect (the ecotoxicological soils database) concentrations to give a more ecologically and environmentally relevant assessment. These steps require some soil related site-specific inputs. The input parameters are dependent upon the metal under consideration, but are generally readily available soil parameters likely to be determined in routine soil analyses.

The data that sit behind the sheet and are used in the calculations (FORMAT, SHEET, UNHIDE to see these) are from the EU Risk Assessments and Voluntary Risk Assessments which have been performed under the auspices of the Existing Substances Regulations (Directive 793/93EC) and subjected to significant member state peer review. A brief explanation of what these data are and how they are used in the sheet to provide the assessment is given below for each metal. Further reading and references are also given.

Process:

There is a significant amount of terrestrial ecotoxicity data for the metals cadmium, copper, nickel, lead and zinc. Therefore, PNECs can be derived using the statistical extrapolation technique (SSD) rather than the use of assessment factors.

The process outlined in this excel spreadsheet is tiered, with cruder, more precautionary tiers at the beginning of the assessment (Tiers 1-3) and more sophisticated, scientifically robust tiers (requiring more input data) at the end (Tiers 4-5). For some metals it is only possible to do the cruder tiers, whereas for others the recommendation is to undertake the site-specific assessments of the higher tiers. Following completion of each tier, a comparison is made between a concentration at the site of interest and an effect concentration. The ratio of these two values gives a Risk Characterisation Ratio (RCR). A value above one suggests there are potential risks and therefore a move to the next tier is required. On reaching the final tier, if there is still a risk one moves to the next stage of the assessment (beyond the remit of this spreadsheet).

There are two separate considerations for copper, nickel, lead and zinc, an 'added' and a 'total' approach, and both are given in the spreadsheet. The difference between these two approaches is related to the consideration of the background concentration of the metal in the toxicity test and the soil under consideration at the specific site. The ‘added’ approach is based on the assumption that it is *only* the metal added to the soil, and not the metal already present in the soil, that will present a toxicological risk. The background concentration in the soil in the toxicity tests performed in the lab (usually from the control soil) is subtracted from final toxicity statistic (the NOEC or EC10 in this case). When this is undertaken for all the data in the spreadsheet and the HC5 recalculated, this final value is known as the PNECadd and is compared to the site specific soil concentration, which also has had the site specific background metal concentration subtracted (this value is termed the PECadd). The site-specific soil metal background concentration is a required input parameter for the ‘added’ approach. However, relationships between soil texture and metal concentrations in UK soils have also been used in the spreadsheet to give default values were no site specific background concentration is available (Zhao *et al*., 2007).

The ‘total’ approach assumes that all the soil metal, including that from the geogenic and low level anthropogenic sources, may potentially have an ecotoxicological effect. The background metal concentration in the toxicity tests (in the control) are NOT subtracted from the final toxicity statistic. This results in a PNECtotal, which is compared directly with a PECtotal, which is the measured soil metal concentration at the site of interest.

Which approach are we using? We need a single pass/fail result.

Due to the differences in ecotoxicological and soils related data that are available for each metal, the tiers used vary for each metal. For copper, nickel and zinc there is considerable data and developed understanding of behaviour of the metal in soils, therefore a very robust site specific assessment based on metal availability and bioavailability can be made. For lead, there is not quite so much information on bioavailability, and for cadmium there is very little information on bioavailability. The processes behind the tiers for each metal are given in more detail below.

Cadmium

The assessment of potential cadmium risk in soils is solely based upon the total soil cadmium concentration at the specific site of interest. The assessment is based on the ‘total’ approach with no account made for the existing concentration of cadmium in the soil. However, there are two PNECs given in the assessment, the first is for ecological risk or direct effects of cadmium in soil, the second is for the consideration of secondary poisoning based on effects upon higher mammals (Cd RAR). The assessment presented in this spreadsheet is very generic for cadmium, and should be regarded as having considerable uncertainty. There is a strong recommendation to examine local soil conditions in addition to the use of this assessment for cadmium.

Lead

For lead there is significantly more ecotoxicity and fate/behaviour data than for cadmium. It is therefore possible to use a more sophisticated tier in the assessment of potential risk. Both the ‘added’ and ‘total’ approaches can be used for lead.

It is widely acknowledged that the metals in soils used in laboratory toxicity tests are more available, and so produce lower effect concentrations than the same soils contaminated to similar levels in the field. In laboratory toxicity tests the soils are often freshly spiked with soluble metal salts (such as chlorides or nitrates) and are used rapidly after spiking, allowing limited time for metal equilibration. The metals present in field soils tend not be from such soluble sources and have often equilibrated over a significant period, when compared to those used in laboratory tests, resulting in reduced availability. To account for these differences between the field and laboratory, three field soils were collected from industrial sites that had been contaminated over time with lead. At each site samples of the same soil type, but not contaminated with lead, were also collected (Pb VRA).

Three chronic soil toxicity tests were performed on each field contaminated soil and the corresponding uncontaminated soil, but spiked with lead to the same 'total' concentration as the field soil. The differences in toxicity observed between the field and spiked paired soils was conservatively at least a factor of 4.2; that is, the lead in the field soils was 4.2 times less toxic than the lead which had been freshly added as soluble salts to the same soil type. This difference in toxicity between the field and the laboratory is accounted for in the spreadsheet by the use of the leaching/aging factor (FORMAT, SHEET, UNHIDE – NOECdatabases), which is used to multiply the laboratory-generated toxicity statistic. The leaching/aging factor is used to correct PNECadd and PNECtotal into PNECadd,L/A and PNECtotal,L/A.

The differences between the 'total' and 'added' assessments in the spreadsheet are that, while both total and added approaches subtract the concentration of lead in the control from the NOEC before applying the leaching/ageing factor, in the 'total' approach the lead concentration from the control soil is then added back onto the NOEC (NOECdatabases). This is in line with the view in using the 'total' that all the metal in the soil could contribute to potential toxicity.

Due to the limited amount of data on lead behaviour and fate in soils, the assessment presented in the spreadsheet only considers background concentrations and the differences between laboratory and field toxicity.

Copper

There is a significant amount of chronic ecotoxicity and fate/behaviour data for copper in soils enabling the most sophisticated assessment based on availability and bioavailability to be made. In this spreadsheet this represents the use of the highest tier and provides the most ecologically and environmentally relevant assessment.

A leaching/aging factor has been determined for copper, in a similar way to that described for lead. The leaching/aging factor for copper is two, and the details of the experimentation underlying this are given in the Cu Risk Assessment (2007). This factor is used in the same way as for lead, but the assessment does not stop at this point and a further refinement of the data is possible.

In addition to the use of the aging/leaching factor in the assessment is the incorporation of copper availability and bioavailability. An experimental programme with 19 different soil types, representing a range of physico-chemical conditions, was undertaken in which seven types of chronic toxicity test were carried out on each soil. This was to examine the relationships between soil factors and copper toxicity. Linear regression models were then constructed with a number of soil parameters against copper toxicity to certain taxa (plants and invertebrates) and functions (microbial). Significantly strong relationships were observed between copper toxicity and soil CEC, organic carbon and also in part to clay content and pH – and therefore these data are required as input parameters for the site specific assessment on the spreadsheet. Where CEC data is unavailable for the specific site of interest it is possible to use a prediction (calculated in the spreadsheet) based on pH, clay content and organic matter (Helling *et al*., 1964).

The slopes from these linear regression models can be seen in the hidden sheets (NOECdatabases) and are used to normalise the copper soil ecotoxicity database to the specific site conditions (columns AR and AS). This effectively enables a site-specific species sensitivity distribution to be drawn, from which a site specific PNEC can be derived. This step is shown in the hidden sheet PNECdatabase, and includes the assessment factor that has been decided is appropriate by the Technical Committee on New and Existing Substances (Cu Voluntary Risk Assessment, 2007).

Nickel

Like copper, nickel is a metal with a significant amount of fate and behaviour data and ecotoxicological information enabling a relatively sophisticated assessment to made of the potential risks.

However, in contrast to lead and copper, the leaching/aging factor is not a single value. This has been shown experimentally with 16 soils of varying physico-chemical properties to be due to the strong positive relationship of nickel sorption with soil pH above a value of 6. This pH related leaching/aging factor is maximally 3 at soil pH values of 7.5 and minimally 1 at soil pH values below 5. The influence of this factor on the toxicity data can be seen in the hidden sheet NOECdatabases.

In addition to the use of this leaching/aging factor there is opportunity to account for availability and bioavailability of nickel in the assessment. An experimental programme using 16 different soils on which seven different chronic toxicity tests were carried out was undertaken to establish the relationships between soil physico-chemical properties and nickel toxicity. Single linear regressions between the nickel toxicity and soil properties were assessed. It was from these relationships that CEC was determined as a key soil property in governing nickel toxicity; therefore this is a required input parameter for the nickel assessment.

Like copper, the slopes from the regression models can be seen in the hidden sheets (NOECdatabases) and are used to normalise the nickel soil ecotoxicity database to the specific site conditions (columns AR and AS)(Ni RAR, ref). The process is the same as described for copper above.

Zinc

Zinc, like copper and nickel, has a significant amount of related ecotoxicological and fate/behaviour data. The methodologies and experimentation to establish a leaching/aging factor and the linear regression models were very similar. For zinc, the leaching/aging factor is 3, derived from (up to eight) chronic zinc toxicity experiments undertaken on a number of soils (>3).

The linear regression models developed for zinc demonstrated that soil specific pH, CEC and background zinc concentration, all had a significant influence upon the ecotoxicity (Zn RAR, ref). Therefore, these parameters are required as inputs for the assessment of potential risks of soil zinc concentrations. The regression models have been used in the same way as those for copper and nickel and are shown in the hidden sheet NOECdatabases.

Interpretation

The purpose of the European Risk Assessments for metals was to assess the potential risks at a number of scales, but to be within the bounds of the 10-90th percentile of European soil physico-chemical properties. Therefore, the assessments presented within this spreadsheet have only been validated and tested for a range of conditions.

The soil physico-chemical conditions within which the assessments for copper, nickel and zinc have been validated and work are given below in the table.

Metals	Soil pH	Soil Organic Matter (%)	CEC (cmol/kg)	Clay (%)	Background concentration (mg/kg)
Cu	3.0-7.5	0.2-37.3	1.2-36.3	5-51	2-88
Ni	3.0-7.5	0.6-40.0	2.4-36.0	7-46	
Zn	3.7-8.1		5.03-33.0		10-172

The outputs tab in the spreadsheet provides a PNEC, that is, the effect concentration being used in the assessment and the Risk Characterisation Ratio (RCR). If the RCR is greater than one, a potential risk at the site of interest has been identified. This should prompt either a move to the next tier or a move next stage of the assessment (beyond the remit of this spreadsheet).

Glossary of Terms

PEC = Predicted (or in this case usually measured) Environmental Concentration of the metal of interest in the soil

PECtotal = As above, but with no consideration of the influence of the background metal concentration

PECadd = As above, but with the background metal concentration at the site of interest subtracted

PNEC = Predicted No Effect Concentration of the metal, concentration below which exposure to the metal is not expected to cause an adverse effect

PNECadd = As above, but the concentration of specific metal from the control soil in the toxicity test has been subtracted from the toxicity statistic (e.g. from the NOEC or EC10)

PNECtotal = As above, but with no consideration of the influence of the background metal concentration

Leaching/Aging Factor (L/A) = An empirically derived factor used to account for the reduced toxicity of metals observed in the field as compared to the same ‘total’ concentration in laboratory toxicity tests.

RCR = Risk characterisation ratio – the PEC divided by the PNEC.

Available = The amount of metal that is in the soil that is equilibrium with the metal in soil solution

Bioavailable = The fraction of total soil metal concentration that the organism of interest accesses. It is dependent upon soil physico-chemical factors and the organism - its specific pathophysiological characteristics (such as route of entry, duration and frequency of exposure)

Add the following definitions…..
NOEC
EC10
HC5

References and further reading

Cadmium Risk Assessment
Copper Risk Assessment
Nickel Risk Assessment
Lead Risk Assessment
Zinc Risk Assessment

Helling, et al.(1964)

Zhao, F.J., McGrath, S. P. and Merrington, G. (2007) Estimates of ambient background concentrations of trace metals in soils for risk assessment. Environmental Pollution, 148:221-229.

Quick Guide

What will this spreadsheet do?

The purpose of this spreadsheet is to provide an assessment of the potential ecotoxicological risk from metals for a soil at a specific site. It represents a 'first step' in a broader ecological risk assessment, and should therefore not be considered as an isolated pass/fail criterion.

The spreadsheet represents an attempt to bring together the latest scientific understanding in regard to metals behaviour in soil in a format that is useable by regulators and the regulated. There is a fundamental acknowledgment behind this process that risks posed by metals are poorly assessed by singular consideration of the 'total' soil metal concentration and that soil and soil organism factors will influence potential toxicity.

For the assessment of the potential risk of metals in your soil of interest you will need to input some physico-chemical data. The spreadsheet will use this data to give an ecologically and environmentally relevant assessment of the metal risks at your site based on ecotoxicity and fate and behaviour data. The data is from a number of EU Risk Assessments, on which more information can be found by clicking the next tab on the spreadsheet.

What do I do?

You will need to input the total soil metal concentration at your site (on the Input tab). For the assessment of copper, nickel and zinc you will also need to input other data, including soil pH, CEC, organic matter percentage and possible clay percentage.

What does it mean?

The Output tab on the spreadsheet gives PNEC, that is, the effect concentration being used in the assessment and the Risk Characterisation Ratio (RCR). If the RCR is greater than one, a *potential* risk at the site of interest has been identified. This should prompt either a move to the next tier (that is, move down the sheet) or a move to the next stage of your risk assessment (beyond the remit of this spreadsheet).

Glossary of Terms

PEC	= Predicted (or in this case usually measured) Environmental Concentration of the metal of interest in the soil
PECtotal	= As above, but with no consideration of the influence of the background metal concentration
PECadd	= As above, but with the background metal concentration at the site of interest subtracted
PNEC	= Predicted No Effect Concentration of the metal, concentration below which exposure to the metal is not expected to cause an adverse effect
PNECadd	= As above, but the concentration of specific metal from the control soil in the toxicity test has been subtracted from the toxicity statistic (e.g. from the NOEC or EC10)
PNECtotal	= As above, but with no consideration of the influence of the background metal concentration

Leaching/Aging Factor (L/A) = A empirically derived factor used to account for the reduced toxicity of metals observed in the field as compared to the same 'total' concentration in laboratory toxicity tests.

RCR = Risk characterisation ratio – the PEC divided by the PNEC.

Available = The amount of metal that is in the soil that is equilibrium with the metal in soil solution

Bioavailable = The fraction of total soil metal concentration that the organism of interest accesses. It is dependent upon soil physico-chemical factors and the organism - its specific pathophysiological characteristics (such as route of entry, duration and frequency of exposure)

Appendix III Metals – Evaluation of Regimes and Regulations

Dr Rob Parkinson
July 2007

Tasks

1. Perform the assessments for each regime, and report as a summary table, indicating pass/fail with reasons. In the event of any ambiguity in the decision-making process or guidance, outline where and why this maybe.

2. Critically assess the value of the standards and process outlined for that regime in terms of achieving the respective protection goals.

These tasks were carried out using:
Using the 'Generic Guidance for the assessment of soils – Metals'
Data for 53 soils
EU Risk Assessment and Soil Screening Values (SSV) spreadsheet

TASK 1. ASSESSMENTS FOR EACH REGIME

Assessments were conducted for each of the 53 soils by matching the data to the limits as stated in 'Generic Guidance for the assessment of soils – Metals'. The full analysis is presented in the spreadsheet 'Metals assessment spreadsheet RP'

1.1 Procedure
Soil properties were compared to the limit values for each of the following regimes:

A. Sludge (Use in Agriculture) Regulations 1989
B. Sewage Sludge Code of Practice 1996
C. EC Sludge 3rd Draft 2000
D. Compost Quality Protocol
E. Waste Management Licensing Regulations 1994
F. BSI Topsoil 2007
G. EU Risk Assessment Values 2006

For Regimes A-F, direct comparisons were made between the soil data and the pH dependent limit values given in the respective regimes. Results are presented as Pass or Fail for the soil and the outcome for each metal for which data was available. For Regime G, the SSV spreadsheet was used to generate Pass or Fail outcomes for Total and Added regimes (see guidance notes contained with the spreadsheet for further information on regimes and criteria).

1.2 Generic issues

1.2.1 Soil pH

Soil pH is a key factor influencing metal availability in soils, a fact reflected in the changing limit values for some metals often found in elevated concentrations in materials applied to soil, such as zinc, copper and nickel. Some approaches (for example, EC Sludge 2000) discriminate for all six metals (zinc, copper, nickel, cadmium, lead and mercury) while the UK based approaches only discriminate for zinc, copper and nickel.

There are critical questions to be asked when close to the threshold; for example, 6.03 for Soil 26. The tables are in some cases ambiguous, for example there is an overlap between categories 5.5 – 6.0 and 6.0 – 6.5. None of the regimes extend below 5.0, hence a soil with a pH <5.0 would presumably not be considered suitable for use in this context (sludge etc return to land).

The BSI regime only specifies three metals, and does not extend below pH 5.5 for any metal. There is hence a problem with this regime when there is a high cadmium content, which gives failure in all other regimes (see Metals Pass/Fail spreadsheet).

1.2.2 Threshold values

In the data set these are reported to two decimal places – so assumes rounding will occur when comparing with the individual regimes. What happens when a soil passes but is equal to the threshold? Should the thresholds be taken as absolute, or should

1.2.3 Missing values

There will always be missing value situations, for which procedures are required. What to do when there are missing values? In this data set there was no data for mercury, despite critical values being specified in most of the regimes. Total lead data is available for 10 soils, and nickel data for 17 of the 53 soils. There is a question as to what should be the minimum metals data requirement in order to make an objective assessment as to whether a soil passes or fails each test.

1.2.4 Soil texture

There is a mismatch between texture classes in UK and EU classifications. In this assessment, percentage clay was matched to the nearest equivalent EU textural class, but often the textural class name did not correspond (see Table 1). Agreed consistency of approach is needed prior to implementation of a system that utilises texture to assess metal limits. Texture data was absent for four soils.

Table 1. Texture class and clay percentage in test soils

Texture EU	% clay in EC classification	% clay in test soils	Texture UK
Clayey	40	-	-
Fine loamy	30	30	zcl
Fine silt	25	23, 24.7	cl, zcl
Coarse silt	20	20, 20.3, 20.7	scl, cl, scl
Coarse loam	15	16.3, 14.0	sl
Sandy	7	7, 7.7, 6.0	sl, ls
Peaty	5	-	-

1.2.5 Background metal concentration

Background metal concentration was only used for the EU SSV regime. Initial status (pre-sludge or waste application) can be an important guide to the potential of a soil to accept further contaminants, but in not included in the UK regimes.

1.2.6 Cadmium

The EU Risk Assessment for cadmium is direct toxicity/secondary poisoning, not total/applied, in contrast with other metals. Hence the interpretation differs between metals in this regime.

1.3 Sample specific issues

Several specific issues arose when completing this metals assessment. In some cases the issue arose on a number of occasions, and only the first is reported here. These are listed below, with a brief commentary.

Soil 145. Threshold – action to take when soil is on a threshold? In this case, zinc for EC Sludge 2000, soil does not exceed threshold, but exactly matches. Were there any cases when the threshold was exactly met with one metal, but passed on all others?

Soil 55. Fails all regimes except BSI, which does not have a numerical criterion for cadmium.

Soils 341, 445, 447, 458. Cannot make a judgement for BSI topsoil, as no relevant data.

Soil 37 Background>total Zn and Ni, hence –ve RCR with EU Risk Assessment.

Soil 51. Zn total EU risk assessment RCR =1.00.

Soil 341, 445. Assumed 20% clay.

Soil 447. Assumed 16% clay.

Soil 458. Assumed 6% clay.

TASK 2. ASSESSMENT OF THE STANDARDS AND REGIMES

The interpretation below refers to issues raised in the 'Generic Guidance for the assessment of soils – Metals' paper. Refer to that paper for full task details, tables and questions. Data analysis is given in the 'Metals assessment spreadsheet RP' excel file.

2.1 Sewage Sludge Regulations

2.1.1. Sludge Regulations (1989)

Given soil pH and total metal concentration, pass/fail assessment is unambiguous. In total, 21 of the 53 soils failed. Key data (zinc, copper) was missing for four soils, in which case pass/fail is not meaningful in terms of the criteria. Although in this case no soils were on the pH threshold, that is 5.00 or 6.00, the pH classes as presented (5.0<5.5; 5.5<6.0 etc) give ambiguity at the threshold.

Question: What is the minimum metals dataset required for a meaningful assessment? It could be argued that the absence of any of the specified metals from the analysis would invalidate an assessment.

2.1.2 Sewage Sludge Code of Practice 1996

Due to the lower zinc limits, more soils failed that under the Sludge Regulations regime (23 fails). There is a potential soil pH threshold criteria ambiguity (5.0-5.5; 5.5-6.0).

2.1.3 EC Sludge 3rd Draft 2000

Due to the more stringent limits (which are pH dependent for cadmium) 42 of the 53 soils failed (see 'Metals assessment spreadsheet RP' for details). Again, there is a potential soil pH threshold criteria ambiguity (e.g. 5.0<6.0; 6.0<7.0).

2.1.4 Are the protection goals being met?

No additional information was available ('*Published guidance suggests that additional physico-chemical properties that would be collected along side the metals data would include; soil pH, available nitrogen, phosphorous and potassium and SOC'*), and if it were, extensive guidance would be needed on interpretation at/near the thresholds. For example, Soil 145 is on the cadmium threshold, but passes other metal limits. Additional soil data would only be useful if information was available on heavy metal loading from additional materials that will be returned to the soil in the near future. Otherwise, the criteria can be used in a 'hard and fast' manner as they stand. This would avoid the issue of potential bias that might be introduced when expert judgment is being used.

Crucial to the assessment of whether regimes meet protection goals is the interpretation of 'harmful effect' (Sewage Sludge Regulations) and 'negative effect' (EC Sludge 3rd Draft 2000). The latter explicitly includes consideration of a wider range of target organisms/environments, and refers to the 'long-term quality' of the soil. To make a comprehensive assessment, it would be necessary to have access not only to additional physico-chemical data, but also long-term records of background and added metal concentrations.

The question 'Are the protection goals being met?' cannot be answered comprehensively here. A qualified response can be given, if it is accepted that the metal concentration limits as specified in the various regimes are based on a full understanding of the soil ecosystem responses to metal additions. Vulnerability to long-term damage depends not only on soil physico-chemical properties and biological resilience, but also on metal concentration and availability in the material to be added to the soil. Hence complete evaluation would require data to characterise the added waste materials.

2.2 Compost Quality Protocol

This protocol states that 'metal analysis required….when the predicted concentrations approach 75 per cent of the limit value'. Hence failure (23 of the 53 soils, same limits as Sewage Sludge Code of Practice 1996) would prevent the use of compost, even if the compost was low in added metals (and might dilute those present in the soil). No additional assessment of 'approaching 75 per cent of the limit values' was conducted in this exercise. Further clarification of these procedures is needed for meaningful interpretation. For example, to calculate predicted topsoil concentration after compost addition, dilution depth and soil bulk density needs to be known. For this regime, full adherence to the protection goals would require compost analysis and proposed application rate.

2.3 Waste Management Licensing Regulations

Additional physico-chemical data were not available for this assessment. As previously observed, detailed interpretation guidance would be needed to implement this requirement. In the absence of physico-chemical data to characterise the waste, no judgments can be made relating to ‘agricultural benefit’ or ‘ecological improvement’ under this regime.

The protection goals state that all activity must be carried out in a manner that will not harm the environment –that is ‘without risk to water, air, soils and plants and animals’. Are the protection goals being met? No, as a judgment regarding the extent of risk can only be made with additional information (see Table 2). Full adherence to the protection goals stated in the regime would require analysis of the waste to be returned to land, together with background soil data. Only then would it be possible to assess whether an application of waste is ‘without risk to water, air, soil, plants and animals’.

2.4 BSI Topsoil

This regime (Table 2.6) only requires data for zinc, copper and nickel. Sixteen of the 53 soils failed. There is ambiguity in the limit values, as the data in Table 2.6 states that the concentration should be less than a given value, while the table caption notes ‘that the metal concentrations should not be exceeded’. Are the protection goals being met? Using the stated limit values, which are broadly in line with those derived for sewage sludge, the goal of minimising impacts due to presence of phytotoxic concentrations of copper, zinc and nickel has been met. However, no data is presented for ‘chemical contaminants (human health and the environment)’, nor thresholds specified.

2.5 EU Risk Assessment Value and UK Soil Screening Values (SSV)

The example soils were assessed on a pass/fail basis using the EU Risk Assessment approach given in the SSV spreadsheet in order to facilitate comparison with the UK regimes. It must be emphasized that guidance in the SSV spreadsheet states that this approach gives an indication of potential ecotoxicological risk, and that this should not be used as an isolated pass/fail test.

The approach is considerably more sensitive than those previously carried out in this assessment as selected soil properties - pH, background and total metal concentration, organic matter and clay content – are used to calculate a risk characterisation ratio (RCR) for each soil, based on PEC/PNEC (see SSV spreadsheet for further information). An RCR >1.0 indicates a potential ecotoxicological risk, and for the purposes of this assessment has been classified as a fail.

Background metal concentrations are included in this approach, such that the risk assessment distinguishes hazards associated with total and added metals. 41 soils ‘failed’ on the basis of total metal risk, while 39 ‘failed’ for added metal risk. In several cases (for example Soils 195, 196 - see Metals assessment spreadsheet RP’) total metal concentrations were less than background, resulting in a negative RCR. This reflects uncertainties due to soil sampling and metal analysis procedures.

If RCR values >1.0 are taken as triggers to further assessment, then this more rigorous approach with a sound technical underpinning offers the opportunity to develop a sensitive and sophisticated toolkit for soil quality assessment. However, the action taken when RCR values exceed 1.0 will require the development of a comprehensive protocol.

Are the protection goals met? In a generic sense yes, more so than the other regimes, although it must be emphasised that 'failure' in this context is part of a tiered approach that requires in-depth evaluation of a soil's ability to satisfy quality criteria relating to its ability to 'sustain plant and animal productivity, maintain or enhance water and air quality, and support human health habitation'. Does this include soil biological health? Finally, there would be a requirement to assess botanical status if the site were adjacent to a designated area (such as a Site of Special Scientific Interest).

3. Concluding comments

There are a number of more philosophical arguments relating to definitions of protection goals as specified in the various regimes that have not been discussed in detail in this Metals assessment. These relate to the assessment of risk in the context of application of metals to soils. For example, it could be argued that any addition of cadmium, particularly in a naturally low cadmium soil, is not 'without risk', particularly when we do not know the full, long-term response of the soil ecosystem to such additions. A further issue relates to the desirability of exceeding the thresholds under a given regime. If a soil is close to a threshold, is it acceptable to apply a material at a 'standard rate' that could take the soil over the threshold following waste application?

Table 2. Required and additional information to assess compliance with protection goals

Regime	Required information	Additional Information
Sludge (Use in Agriculture) Regulations 1989	pH Zn, Cu, Ni, Cd, Pb, Hg	Soil - available N, P and K, SOC, % clay Metal content of applied material
Sewage Sludge Code of Practice 1996	pH Zn, Cu, Ni, Cd, Pb, Hg	Soil - available N, P and K, SOC, % clay Metal content of applied material
EC Sludge 3rd Draft 2000	pH Zn, Cu, Ni, Cd, Pb, Hg	Soil - available N, P and K, SOC, % clay Metal content of applied material
Compost Quality Protocol	pH Zn, Cu, Ni, Cd, Pb, Hg	Soil - available N, P and K, SOC, % clay Metal content of applied material Application history to assess 75% threshold
Waste Management Licensing Regulations 1994	pH Zn, Cu, Ni, Cd, Pb, Hg	Soil - N, P, K, Mg, SOC, % clay, biological status? Runoff/leaching potential? Metal content of applied material
BSI Topsoil 2007	pH Zn, Cu, Ni	Cd, Pb and Hg not required but desirable Other 'chemical contaminants'?
EU Risk Assessment Values 2006	pH, % clay, SOC Zn, Cu, Ni, Cd, Pb, Hg	Soil - CEC, N, P, K, Mg, SOC, % clay, biota and botanical status? Runoff/leaching potential?

The focus of this review has been to carry out a comparative evaluation of the selected regimes for a suite of soils, based on a restricted (but realistic) data set. In all cases the stated aim of the regime, or level of protection, cannot be assessed fully without a more extensive data base which would include soil background data and waste characterisation. Table 2 lists the key data needed. This list is not comprehensive, but should be regarded as indicative, particularly when a regime specifies soil health/quality/function considerations. In such cases it could be argued that risks can only be minimised if application regimes (timing, site conditions and so on) are known. This is clearly beyond the scope of most of these regimes, and would lead to them being so impractical as to be unmanageable.

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