Department for Environment, Food and Rural Affairs
and The Environment Agency

ASSESSMENT OF RISKS TO HUMAN HEALTH FROM LAND CONTAMINATION:

AN OVERVIEW OF THE DEVELOPMENT OF SOIL GUIDELINE VALUES AND RELATED RESEARCH

Publishing Organisation
Environment Agency, Rio House, Waterside Drive, Aztec West, Almondsbury, BRISTOL, BS32 4UD.

Tel: 01454 624400 Fax: 01454 624409

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Statement of Use
This publication serves as an introduction to the other reports in this series. It sets out the legal framework, in particular the statutory definition of contaminated land under Part IIA of the Environmental Protection Act 1990; the development and use of Soil Guideline Values; and references to related research. The report has been written for technical professionals who are familiar with the risks posed by land contamination to human health but who are not necessarily experts in risk assessment. It is expected to be of use to all parties involved with or interested in contamination, but in particular to those concerned with the assessment of land contamination.

Keywords
Soil Guideline Values, land contamination, risk assessment.

Environment Agency Contact
Ged Duckworth, Land Policy Manager, Rio House, Waterside Drive, Almondsbury, Bristol BS32 4UD

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Environment Agency R&D Dissemination Centre, c/o
WRc, Frankland Road, Swindon, Wilts SN5 8YF

tel: 01793-865000 fax: 01793-514562 e-mail: publications@wrcplc.co.uk

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1 Introduction

1.1 The Contaminated Land Report (CLR) series of documents have been produced by the Department for Environment, Food and Rural Affairs (DEFRA), its predecessor departments, and more recently the Environment Agency, to provide regulators, developers, landowners and other interested parties with relevant, appropriate, authoritative and scientifically based information and advice on the assessment of risks arising from the presence of contamination in soils.

1.2 This report, CLR7, is an introduction to those that follow (CLR8–10). It gives an overview of the development of Soil Guideline Values and related material relevant to the assessment of risks to human health from land contamination.

1.3 CLR8–10 deal with the assessment of risks to human health arising from long-term exposure to soil contamination. They are intended to be used by those responsible for the assessment of land contamination: local authorities; the Environment Agency; "problem-owners" such as landowners and developers; and professional and technical advisers who advise on and carry out investigation, risk assessment and remediation. The CLR series is written for technical professionals who are familiar with the risks posed by land contamination to human health but who are not necessarily experts in risk assessment.

1.4 The CLR series' main purpose is to provide technical material that can be used in support of the application of the statutory regimes addressing land contamination, particularly Part IIA of the Environmental Protection Act 1990 (the contaminated land regime) and development control under the Town and Country Planning Acts. In particular, they are intended to be regarded as "relevant information", and to assist in the assessment of "relevant and available evidence" and "information", for the purposes of paragraphs A.31, B.39 and B.44 - 49 of the Part IIA statutory guidance contained in DETR Circular 02/2000 (Department of the Environment, Transport and the Regions, 2000a).

1.5 CLR7–10 take into account the wider DEFRA and predecessor departments' guidelines on assessing and managing environmental risk (Department of the Environment, Transport and the Regions, Environment Agency and Institute for Environment and Health, 2000).

1.6 It is strongly recommended that each CLR in the series should be read in conjunction with the others. Table 1.1 provides more information on the content of each report. Figure 1.1 shows where these reports fit in the hierarchy of guidance for the assessment of contaminated land.

1.7 This report, CLR7, sets out:

- the legislative context for the use of CLRs including the Part IIA contaminated land regime and the planning system (Section 2);
- the use of Soil Guideline Values in the assessment of chronic risks to human health arising from land contamination, and the background to their development (Section 3);

- approaches to soil sampling, testing and data analysis when using Soil Guideline Values in different regulatory contexts (Section 4);
- a summary of the next three CLRs, which describe in detail the Soil Guideline Values and the technical basis for their derivation, as well as other information relevant to assessment of risks to human health (Section 5).

1.8 The information described in this and the related reports is relevant to many situations where land contamination may be an issue. It is not intended for use solely in connection with the formal requirements of Part IIA of the Environmental Protection Act 1990.

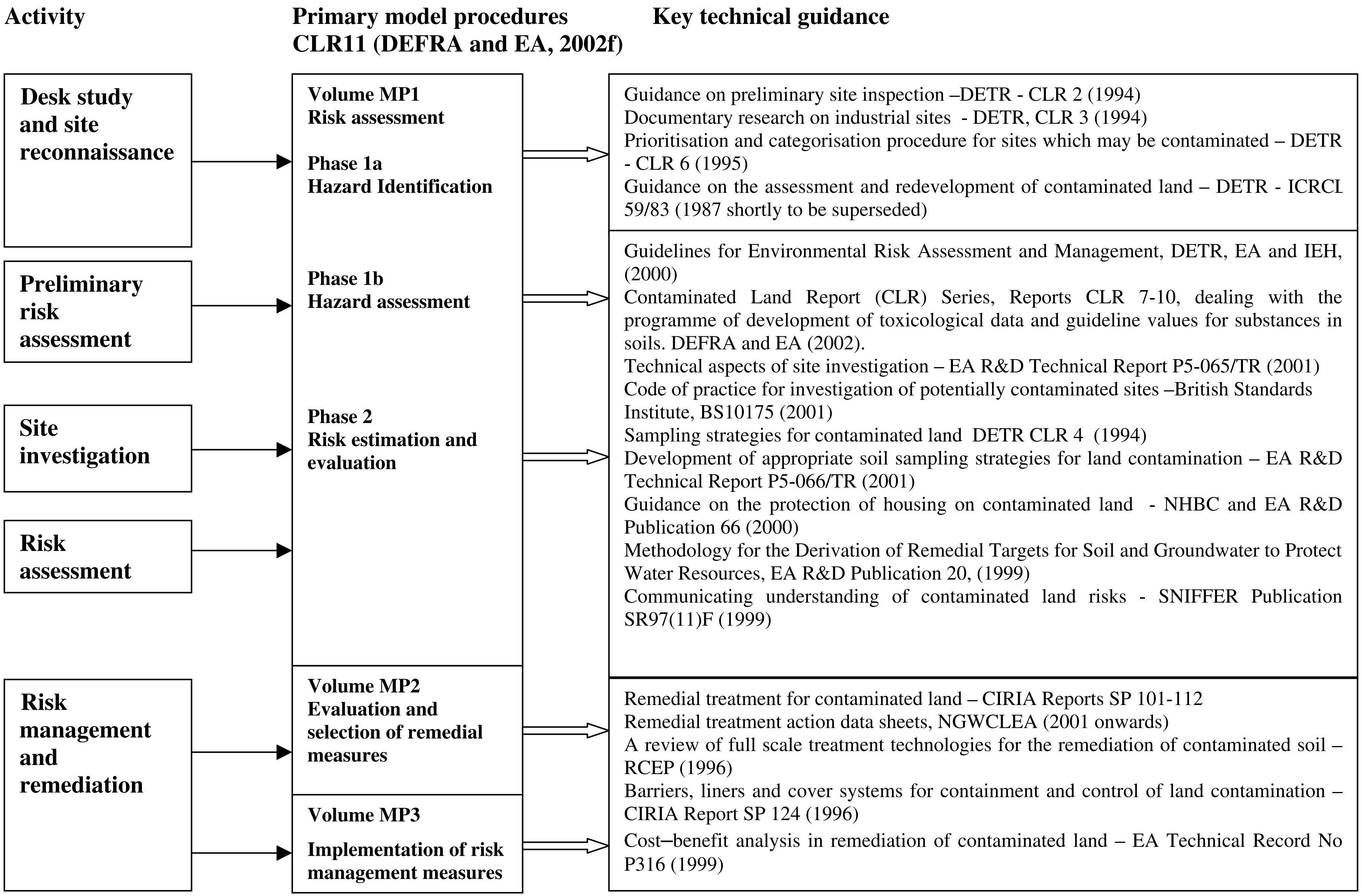
1.9 The information covered by the new CLRs relates primarily to the assessment of the impact of land contamination on human health over an individual's lifetime. Separate guidance is provided for those situations where the cause of concern relates to short-term exposure to high contaminant concentrations (Environment Agency 2002a). In some cases, the assessment process will also need to consider whether other targets of concern, such as controlled waters, ecosystems, buildings and crops or livestock, are at risk. Where such risks are identified, the assessor should use other good practice guidance to evaluate the extent of the risk to these targets and to determine appropriate actions.

1.10 On many sites, transient risks from contamination to site workers during redevelopment or other construction works may be significant. Such risks are within the remit of the Health and Safety Executive and are dealt with by the Health and Safety at Work Act 1974 and regulations made under the Act including the COSHH Regulations. They are not considered here.

Table 1.1 Assessment of risk to human health from land contamination
Key reports from the Department for Environment, Food and Rural Affairs and the Environment Agency

CLR7 *Assessment of Risks to Human Health from Land Contamination: An Overview of the Development of Soil Guideline Values and Related Research*. This serves as an introduction to the other reports in this series. It sets out the legal framework, in particular the statutory definition of contaminated land under Part IIA of the Environmental Protection Act 1990; the development and use of Soil Guideline Values; and references to related research.
CLR8 *Priority Contaminants Report.* This identifies priority contaminants (or families of contaminants), on the basis that they are likely to be present on many current or former sites affected by industrial or waste management activity in the United Kingdom in sufficient concentrations to cause harm; and that they pose a risk, either to humans, building, water or ecosystems. It also indicates which contaminants are likely to be associated with particular industries (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002a).
CLR9 *Contaminants in Soils: Collation of Toxicological Data and Intake Values for Humans.* This report sets out the approach to the selection of tolerable daily intakes and Index Doses for contaminants to support the derivation of Soil Guideline Values (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002b).
CLR9 TOX 1–10. These reports detail the derivation of Tolerable Daily Intakes or Index Doses for the first ten contaminants for which Soil Guideline Values have been determined: arsenic, benzo[*a*]pyrene, cadmium, chromium, inorganic cyanide, lead, phenol, nickel, mercury and selenium (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002c).
CLR10 *Contaminated Land Exposure Assessment Model (CLEA): Technical Basis and Algorithms.* This describes the conceptual exposure models for each standard land-use that are used to derive the Soil Guideline Values. It sets out the technical basis for modelling exposure and provides a comprehensive reference to all default parameters and algorithms used (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002d).
CLR10 SGV 1–10. These set out the derivation of the Soil Guideline Values for the first ten contaminants for which Soil Guideline Values have been determined: arsenic, benzo[a]pyrene, cadmium, chromium, cyanide (free, simple, and complex inorganic compounds), lead, phenol, nickel, mercury (inorganic compounds) and selenium. (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002e).

Figure 1.1 Hierarchy of guidance on land contamination



2 Legal Framework

Town and Country Planning Acts

2.1 Land contamination is a material planning consideration within the planning regime. This means that a planning authority has to consider the potential implications of contamination both when it is developing structure or local plans (or unitary development plans) and when it is considering individual applications for planning permission. Where contamination is suspected or known to exist at a site, a planning authority may require investigation before granting planning permission, or may include conditions on the permission requiring appropriate investigation and, if necessary, remediation (Department of the Environment/Welsh Office, 1994). Further planning guidance will be published by the Department for Transport, Local Government and the Regions (DTLR) in the future. The other primary mechanism is the Part IIA contaminated land regime described below.

Part IIA of the Environmental Protection Act 1990 (the contaminated land regime)

2.2 Part IIA of the Environmental Protection Act 1990 (which was inserted by Section 57 of the Environment Act 1995) has created a new regime for the identification and remediation of contaminated land. This introduced a definition of contaminated land, for the purpose of the regime, and (as regards England) is described fully in DETR Circular 02/2000, which also contains the statutory guidance (Department of the Environment, Transport and the Regions, 2000a). New regulations (Department of the Environment, Transport and the Regions, 2000b) deal with various administrative details. Part IIA has also been implemented in Wales and Scotland, with only minor differences. This CLR uses the references appropriate for England, but similar arrangements apply in Wales and Scotland. The main functions under this regime are exercised by local authorities and, in certain circumstances, the Environment Agency or the Scottish Environment Protection Agency.

2.3 Both Part IIA and the planning regime embrace the "suitable for use" approach. In the context of Part IIA, action is necessary only where there are unacceptable risks to health or the environment, taking into account the current use of the land and its environmental setting.

2.4 Part IIA is intended to complement the planning regime (which deals with risks to new development or land–uses arising from existing contamination). It also complements other regulatory regimes, including the Pollution Prevention and Control regime, Groundwater Regulations, Consents to Discharge and the system of waste management licensing, which control and limit future pollution.

2.5 Reference should be made to DETR Circular 02/2000 for a full description of the Part IIA regime, including procedural steps, the statutory guidance and statutory references. For convenience, the paragraphs below highlight some aspects of the regime as regards human health, to give context for the CLR series.

2.6 Section 78A(2) of the Act defines contaminated land for the purposes of Part IIA as:

> "any land which appears to the local authority in whose area it is situated to be in such a condition, by reason of substances in, on or under the land, that
>
> (a) significant harm is being caused or there is a significant possibility of such harm being caused; or
>
> (b) pollution of controlled waters is being, or is likely to be caused."

2.7 The definition is the subject of statutory guidance issued by the Secretary of State (Department of the Environment, Transport and the Regions, 2000a). Chapter A of the guidance sets the definition of contaminated land within the context of the "suitable for use" approach. It is based on the principles of risk assessment, including the concept of a "pollutant linkage" – a linkage between a contaminant, and a receptor, by means of a pathway. The receptors for Part IIA purposes are listed in Table A of Chapter A, and include human beings. For each receptor the guidance specifies what is to be regarded as "significant harm", and a "significant possibility" of such harm, with respect to the definition of contaminated land in Section 78A.

2.8 For human beings, "significant harm" is defined in Table A as:

> "Death, disease, serious injury, genetic mutation, birth defects or the impairment of reproductive functions.
>
> For these purposes, disease is to be taken to mean an unhealthy condition of the body or a part of it and can include, for example, cancer, liver dysfunction or extensive skin ailments. Mental dysfunction is included only insofar as it is attributable to the effects of a pollutant on the body of the person concerned ....."

2.9 Table B defines "significant possibility of significant harm", in terms of:

> "Human health effects arising from the intake of a contaminant, or other direct bodily contact with a contaminant."

2.10 It sets the conditions to this description:

> "If the amount of the pollutant in the pollutant linkage in question:
>
> - which a human receptor in that linkage might take in, or
> - to which such a human might otherwise be exposed,
>
> as a result of the pathway in that linkage, would represent an unacceptable intake or direct bodily contact, assessed on the basis of relevant information on the toxicological properties of that pollutant.
>
> Such an assessment should take into account:

- the likely total intake of, or exposure to, the substance or substances which form the pollutant, from all sources including that from the pollutant linkage in question;

- the relative contribution of the pollutant linkage in question to the likely aggregate intake of, or exposure to, the relevant substance or substances; and

- the duration of intake or exposure resulting from the pollutant linkage in question.

The question of whether an intake or exposure is unacceptable is independent of the number of people who might experience or be affected by that intake or exposure.

Toxicological properties should be taken to include carcinogenic, mutagenic, teratogenic, pathogenic, endocrine-disrupting and other similar properties."

2.11 Chapter B of the statutory guidance sets out further factors, such as consideration of synergistic effects, which must be taken into account when the local authority makes the formal determination that land is contaminated land (see "Making the Determination", in particular B.39, B.40 and B.41).

2.12 Assessment of "significant possibility of significant harm" is covered by paragraphs B.45 to B.49.

2.13 Paragraph B.47 sets the formal use of "guidelines for concentrations of the potential pollutants" in the determination process. It states that, subject to conditions set out in other parts of the guidance, e.g. paragraphs B.48 and B.49:

> "To simplify such an assessment of risks, the local authority may use authoritative and scientifically based guidelines for concentrations of the potential pollutants in, on or under the land in pollutant linkages of the type concerned."

2.14 Section 4 of this report provides more guidance on the application of Soil Guideline Values to making determinations of contaminated land under Part IIA.

3 Development of Soil Guideline Values and their use in the Assessment of Risks to Human Health from Land Contamination

3.1 This section provides the general background to the development of new Soil Guideline Values and related work that may be appropriate for use in the new regime, as well as for wider application.

Previous UK guidance

3.2 The UK was one of the first countries to propose criteria for concentrations of certain contaminants in soil in the context of land used for redevelopment. These criteria were based on the work of the Interdepartmental Committee on the Redevelopment of Contaminated Land in the 1980s (ICRCL, 1987).

3.3 Two criteria were presented: "threshold trigger values" and "action trigger values". The threshold trigger value indicated the concentration of a contaminant in soil below which no action was required. The higher, action trigger value indicated the concentration above which action was always required. The two values would therefore bound the region where professional judgement should be used to decide whether action was required and what form it should take. In the event, threshold trigger values were derived for 17 contaminants, but action trigger values were only defined for a proportion of these (ICRCL, 1987).

3.4 The House of Commons Select Committee on the Environment identified problems with this existing guidance in their report on contaminated land in 1990 (House of Commons Environment Committee, 1990). The Committee called for a system of statutory soil quality objectives and standards, more scientifically based guidance, and general improvements in professional standards.

3.5 In 1990 the Government's response to this accepted that more work was needed on the development of guidance in the assessment of land contamination. However, it rejected the idea of statutory objectives and standards covering all circumstances (Department of the Environment, 1990). The Government focused research effort towards the development of more extensive guidance covering a number of different aspects of human health risk assessment, including the development of new Soil Guideline Values. This research was linked to the discussion and development of the legal framework for land contamination.

Factors in developing Soil Guideline Values

3.6 Quantitative guidelines for assessing risks are associated with several scientific problems. There are difficulties in establishing concentrations of contaminants beyond which risks from exposure to these contaminants would be "unacceptable". This requires not only scientific (toxicological) information on the health effects, but also judgement on what is "unacceptable" risk. In addition, soil is only one of the sources of contaminant exposure, and its effect needs to be kept in proportion with the total exposure from all sources. So, Soil

Guideline Values represent a combination of authoritative science tempered with policy judgements.

3.7 Generic Soil Guideline Values must be applicable across a range of soil types and site conditions. They must be firmly based on the underlying, but incomplete, science of contaminant behaviour, human activity patterns and contaminant toxicology. All of these factors make it difficult to derive generally applicable criteria. "Worst– case" assumptions could be used to overcome some of the problems but they can result in criteria that are impracticable or over-conservative.

3.8 Nevertheless, quantitative generic guidelines for concentrations of contaminants in soil, based upon standard assumptions, can serve a useful purpose in encouraging a transparent and consistent approach. They can also be helpful in focusing resources on situations that require more detailed assessment. These, together with careful assessment of the available scientific information and a general application of a precautionary approach, are the principles underlying risk assessment and the CLR series being developed under the DEFRA and Environment Agency research programmes.

Comparison with approaches in other countries

3.9 Various countries have set different quantitative criteria and developed different risk assessment models for the assessment of risks to human health from contaminated land. To a large extent, these reflect the particular environmental and legal conditions that exist in those countries, so that simple comparisons of quantitative criteria used in different countries can be misleading. Such comparisons can only be made with a full understanding of the different contexts within which criteria have been chosen. It also follows that it is usually inappropriate to apply quantitative criteria outside the country, and therefore the context, for which they are intended. In some countries, different assumptions have been used to reflect different behaviour patterns, local soil types or other technical factors. An international review of some of the early developments in the use of quantitative criteria for contaminated soils is reported in Visser (1995). This identified two components that are fundamental to the relevance of the criteria.

3.10 The first component relates to the policy context. Most countries have made key policy choices over whether the policy objective is to assess sites on the basis of risk for all possible future uses ("multi–functionality"), or on the basis of a particular use ("suitable for use"). This latter approach has been adopted in the UK and is increasingly common elsewhere.

3.11 For some countries, in some circumstances, the assessment of sites may relate to the amount of contamination measured against some pre–determined concentration, for example, background or a pre-set "critical load". In the UK this is most commonly only considered relevant for assessing "new" or additional contamination (for example, in the context of the Pollution Prevention and Control (PPC) Regulations).

3.12 The second component relates to the circumstances in which the criteria are to be applied. In general, the criteria are used in two ways:

- Deciding whether to take action on a particular site
- Determining remedial objectives

3.13 The first type of criterion, which would fit into a regulatory context for taking action on problem sites, could relate to the concentration above which land might present "unacceptable" risk, that is an intervention value. The second could relate to a "remediation standard" or "target value". This could be either a standard to which sites could be treated, or a longer–term goal for land as a whole. In some countries, intervention and target values are identical. In others, regulatory "intervention" takes place at a higher concentration of contaminants in soil than the "clean–up" standard. It is important to maintain the distinction between these two types of criteria.

The new Soil Guideline Values

3.14 The primary purpose of the Soil Guideline Values, for which this report provides an overview, is as "intervention values" in the new regulatory framework for assessment of human health risks in relation to land-use (the ICRCL trigger and action values also relate to intervention). The new Soil Guideline Values are intended to provide a means of assessing chronic risks to human health in accordance with paragraph B.47 of the statutory guidance. This will assist local authorities in making determinations of contaminated land on the grounds of there being a "significant possibility of significant harm" (see paragraph B.38). However, their use for Part IIA purposes is subject to the provisions of the statutory guidance and other legal requirements and they cannot be applied in isolation.

3.15 The Soil Guideline Values are also expected to be useful in the context of the planning regime. Again, they are not binding standards, but may be used to inform judgements about the need for action to ensure that a new use of land does not pose any unacceptable risks to the health of the intended users. It is intended that Soil Guideline Values will replace ICRCL values.

3.16 The Soil Guideline Values can also be used to inform the selection of remediation standards or target values for individual sites. For Part IIA, Chapter C of the statutory guidance deals specifically with the standard of remediation, which relates to the overall aim of ensuring that land is no longer contaminated land. Generally, for example under planning as well as Part IIA, the design of sampling and analysis needs to be sufficient to give confidence that concentrations on the site meet defined remediation objectives.

3.17 For some substances, such as genotoxic carcinogens, there is no threshold below which adverse effects may not occur. The Soil Guideline values for these substances represent a level at which there is a minimal risk. The settings of remediation objectives for these substances would normally be made in accordance with the ALARP (as low as reasonably practicable) principle. Subject to this requirement, the overall objective should be to minimise future exposure from all sources.

3.18 When using SGVs in the context of Part IIA, the standard of remediation is constrained by the statutory guidance (Chapter C).

4 Approaches to Soil Sampling when using Soil Guideline Values in Different Regulatory Contexts

4.1 As indicated in Section 3, a single Soil Guideline Value for a substance may be used in more than one regulatory context. This section sets out an approach to the soil sampling strategy and subsequent data analysis in the context of the Part IIA regime, for which the Soil Guideline Values have been primarily developed. It also recognises the potential use of Soil Guideline Values in the planning regime.

General considerations

4.2 In order to use a Soil Guideline Value, an assessor must be able to characterise the site in question sufficiently such that:

- relevant contaminants have been identified;
- the area of land where the contaminants exist has been identified;
- the site has been characterised to the extent that the conceptual model has been validated, and, if appropriate, the existence of a pollutant linkage has been established;
- the concentrations and prevalence of contaminants have been estimated to the extent that they allow a robust comparison to be made with the Soil Guideline Value.

4.3 Guidance on relevant contaminants, which could relate to the history of the site and to the receptor that may be affected, can be obtained from CLR8 (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002a) and the Industry Profiles (Department of the Environment, 1995/96). Guidance on good practice in the design and implementation of investigation can be obtained from a range of documents (British Standards Institute, 2001; Environment Agency, 2001a). General advice on sampling strategies is currently available (Department of the Environment 1994; Environment Agency 2001b). The Environment Agency has consulted on the issue of laboratory standards and is introducing an accreditation scheme and standards for analytical data. The importance of obtaining good quality data cannot be emphasised too strongly; it requires good quality assurance procedures during both sampling and analysis.

4.4 There are many uncertainties associated with soil sampling and analysis. The level of confidence that can be assigned to contaminant measurements depends on sampling and analytical errors and the extent to which these are controlled successfully. So, the range of possible concentration values that can be attributed to an area of land is dependent on measurement uncertainty, as well as variation of concentrations within the test area of land. Careful zoning of a site may allow narrower ranges of possible concentrations to be assigned for individual zones, because activity-related heterogeneity may be less.

4.5 When applying statistical tests, care needs to be taken to assess if the data set is sufficiently representative, especially when only a small number of samples have been taken. Other aspects that need to be considered, in addition to analytical uncertainties, are:

- Standard of soil sampling and collection techniques
- Sample preservation prior to arrival in laboratory
- Selection of most appropriate test method
- Stated bias and precision of laboratory test results
- Application of an appropriate level of quality assurance to all aspects of the process

Statistical treatment of samples

4.6 Meaningful comparison of a data set of contaminant concentrations with a Soil Guideline Value requires consideration of the area of land from which the data set is drawn and the number of test results that make up the data set, as well as the actual values involved.

4.7 When designing a site investigation, it is not practicable to sample the entire soil mass. A limited number of samples are taken to represent the whole of an area of interest, so it is necessary to use statistical techniques to enable decisions about the area being investigated. Where one or more areas of a site appear to have different characteristics from the remainder of the site, an assessor may divide the site into zones of similar character that can be considered independently of each other. Zoning may take into account such characteristics as variations in soil properties or historical, existing or proposed new land–uses.

Use of Soil Guideline Values in Part IIA

4.8 The statutory guidance sets out the circumstances under which it is reasonable for a local authority to use Soil Guideline Values in determining that land is contaminated land on the basis that there is a significant possibility of significant harm. Paragraphs B.47 to B.49 set out the basis and conditions for their use.

4.9 Where a Soil Guideline Value has been published for a particular contaminant, a local authority may consider its use in making a determination under Part IIA. Published Soil Guideline Values should only be used after the assessor has satisfied him/herself that the exposure and other conditions assumed are appropriate for the site. Detailed information on land–use and exposure assumptions are provided in CLR10 (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002d).

4.10 When considering how many data points are needed for an area of land to provide a representative indicator of receptor exposure to the contaminant, the concept of averaging areas needs to be applied. An averaging area (or area of interest) is that area (together with a consideration of depth) of soil to which a receptor is exposed or which otherwise contributes to the creation of hazardous conditions. The soil in the averaging area will contain variable concentrations of contaminants, which, when averaged across the area, will provide a representative indicator of how much contaminant the receptor is exposed to. Defining such areas requires knowledge of the behaviour pattern of the receptor. For example, a single garden on a housing estate may be an appropriate averaging area for a child living in the house. The entire area of an abandoned industrial site that forms an informal play area for neighbourhood children could also be an appropriate averaging area to assess the risk from contaminants. More detailed guidance on sampling strategies is available (Environment Agency, 2001b). It describes methods of defining sampling grid sizes to allow detection of given areas of interest (that is, contaminated areas) to a stated degree of statistical confidence.

4.11 Once the results are available for an appropriate averaging area, the key question is whether the mean measured contaminant concentration is greater or less than a published Soil Guideline Value (or a comparable figure from a site-specific study). Even where all the analytical results contributing to the mean lie below (or above) the Soil Guideline Value, errors in estimating the "true" mean from a limited number of samples could result in incorrect conclusions being drawn. In all cases, the statistical tests outlined below and in Appendix A should be followed.

4.12 Contaminant concentrations vary across a site, and sampling and analysis will introduce measurement errors. As a result, the mean concentration determined from a limited number of samples will have uncertainty associated with it, and will not necessarily equal the true mean concentration at the site. A comparison between a mean measured concentration and the Soil Guideline Value must take this uncertainty into account. Appendix A and Annex 1 set out a mean value test which compares the Soil Guideline Value with the upper 95th percentile of the mean measured concentration. Where the mean value test is applied, and the data passes the test, local authorities may consider that the site requires no further action. Conversely, where a set of data fails the mean value test, a local authority can make judgements about the benefits of undertaking more comprehensive sampling where only a small number of data points exist, or move towards determination as contaminated land under Part IIA, assuming that a significant pollutant linkage has been identified. The mean value test should be applied to the data set for each of the averaging areas being considered.

4.13 In some data sets, individual concentrations may have been measured at particular locations that are much higher than the rest of the data. Decisions need to be made on whether these concentrations fall within the maximum of the range of values that can be expected from the sample population, or whether they are indicative of an area of higher contamination (in effect, a different population with a higher mean). Data points that do not fall within the expected distribution of measurements for the sample population are termed "outliers". The maximum value test (see Appendix A and Annex 2) can be used to define whether the maximum measured concentration in the soil should be classified as an outlier, and hence whether additional investigation might be warranted in the vicinity to clarify further the extent and nature of the contamination.

4.14 A local authority will also need to consider the local context when using Soil Guideline Values. If a substance occurs naturally at high concentrations in a locality, as a result, for example, of the mineralogy of the subsoil, then the local authority may wish to consider whether a site-specific risk assessment would be a more appropriate way to proceed. This would allow the authority to consider matters such as the bioavailability of the substance and local receptor behaviour and characteristics.

4.15 If a Soil Guideline Value has not been published, then the local authority should consider a risk assessment at the site using site-specific criteria. Guidance is in preparation by the

Environment Agency in this respect (Environment Agency, 2002b and CLR9 and CLR10 of this series of reports).

Use of Soil Guideline Values in the planning regime

4.16 The planning regime recognises that land contamination is a material planning consideration. The planning authority should satisfy itself that potential contamination is assessed properly, and that any necessary remediation is undertaken as a part of the development. Investigation may need to be carried out in advance of granting planning permission or, where appropriate, planning permissions should include site investigation and remediation conditions. Under the "suitable for use" approach, risks should be assessed, and remediation requirements set, on the basis of the proposed use. The same Soil Guideline Values and statistical procedures appropriate to Part IIA can be used to inform an assessment of the need for action to make a site suitable for some future use. Where remediation is found to be necessary, remedial objectives should be set that ensure achievement of a standard clearly below the appropriate Soil Guideline Value (that is, after remediation, the upper 95th percentile of the measured mean concentration must be lower than the Soil Guideline Value, or any site-specific criterion).

Use of Soil Guideline Values where capping layers are provided

4.17 Soil Guideline Values have been developed from a model which assumes that the sensitive receptors (adults or children) will be exposed to the given concentration of contaminant in the soil at the ground surface. The degree to which the introduction of a capping layer over the contaminated soil may reduce exposure should be assessed on a site-specific basis. Such an assessment must take into account the likely human and natural impacts on the cap.

5 Summary of Reports CLR8, 9 and 10

5.1 The reports described in this document provide information on:

- potential contaminants for assessment of land, in particular those which may be relevant to human health risks – in CLR8;
- establishing the toxicological properties of soil contaminants which underpin the derivation of the Soil Guideline Values, or which can be used more widely to assess unacceptable intake of, or direct bodily contact with, soil contaminants – in CLR9;
- the toxicological properties of certain contaminants – in TOX reports;
- assessing the exposure of humans to soil contaminants relevant to particular uses of land, for the purposes of deriving Soil Guideline Values – in CLR10;
- Soil Guideline Values for concentrations of contaminants in soils in relation to harm to human health – in SGV reports.

5.2 These reports are summarised below; reference should be made to the full report for further information.

CLR8: Potential contaminants for the assessment of land (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002a)

5.3 One of the first steps necessary in deriving assessment criteria is to identify the substances for which criteria might be appropriate. ICRCL 59/83 (Interdepartmental Committee on the Redevelopment of Contaminated Land, 1987) covered 17 contaminants that are encountered on many sites. However, there are many more potential contaminants that are significant in terms of human health. DEFRA has concentrated its initial work on the existing ICRCL substances, but at the same time commissioned a study to identify those other contaminants which would be relevant to the UK.

5.4 The contaminants selected are the contaminants most likely to be relevant for the assessment of land and which need to be considered within the assessment of individual sites. CLR8 covers contaminants relevant to assessment of risks to a range of receptors.

5.5 There are two key criteria for the selection of potential contaminants, both of which relate to the potential risk posed by the contaminants. The first criterion is their likely presence, in significant concentrations, on land that has been, or is, in industrial use. Thus, if a substance, however hazardous or toxic, is not found, or rarely found, it has not been considered for generic selection. The Industry Profiles (Department of the Environment, 1995/96) have been used as an information source to judge the prevalence of different contaminants on sites of various former uses and therefore their overall potential impact on a national basis.

5.6 The second criterion for selection is that the contaminants must present a potential risk to one or more receptors: human health, the water environment, ecosystems, or the integrity of construction and building materials. The particular risk depends on the nature of the hazard, the probability of exposure, the pathway by which exposure occurs and the likely effect on the receptor.

5.7 The report includes a matrix drawn from the Industry Profiles (Department of the Environment, 1995/96) that indicates which contaminants could be associated with certain industrial uses of land; and a further matrix indicating the receptors potentially affected by these contaminants. The lists of contaminants included should not, however, be regarded as a blanket list for any particular site investigation. By the very nature of the use to which the land is put, some contaminants will be of no significance on certain types of site. Other sites, however, may be contaminated by significant concentrations of particular substances that may not qualify as one of the "potential contaminants", because their general occurrence may be infrequent, and, as a consequence, they fail to meet the first criterion.

5.8 Those contaminants which satisfy the two criteria described above, and which may pose a risk to human health, are identified in the report as forming the group of candidate substances for research work to review the toxicological data and derive Soil Guideline Values. However, it is recognised that knowledge about contaminants will develop with time, and new substances will continue to be added to the research programme when it is appropriate.

CLR9: Contaminants in soils: collation of toxicological data and intake values for humans (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002b)

5.9 The starting point in the development of human health assessment criteria is the characterisation of the potential health risks associated with exposure to contaminants and the identification of "intakes" that do not pose a significant risk of significant harm, based on toxicological information.

5.10 In practice, contaminants fall into two categories. A distinction must be made between chemicals with critical health effects for which there is considered to be a threshold and those chemicals for which a threshold for health effects cannot be assumed. For the purposes of deriving Soil Guideline Values, chemicals that exhibit an effect threshold can be ascribed a tolerable daily intake (TDI). Those which have no threshold carry a putative risk at any level of exposure, but are allocated an Index Dose, which represents a minimal human health risk. SGVs for these substances are derived from Index Doses that represent a minimal risk level. Exceedance of the ID, even in the short term, indicates an increased level of risk to health, which is not acceptable. For non-threshold chemicals, exposure should be kept to a level *as low as reasonably practicable* (ALARP). The term Index Dose has been used for non-threshold-effect chemicals in this work to flag the ALARP principle for these substances.

5.11 In toxicological work, TDIs are estimates of the amount of contaminant, expressed on a body weight basis, that can be ingested daily over a lifetime without appreciable health risks. TDIs can therefore be used together with other information on intakes from sources other than soil, and on the mechanisms of exposure to soil, to assess risks to human health.

5.12 The general approach to deciding on a TDI or Index Dose is described in the report. Essentially this starts with a review of health criteria recommended for a contaminant by various authoritative organisations, such as the Joint Food and Agriculture Organization (FAO)/World Health Organization (WHO) Expert Committee on Food Additives (JECFA) and the WHO. This may lead to a conclusion as to the most appropriate value in the context of Soil Guideline Values for contaminants in soil. In those cases where no authoritative TDI exists, a value may need to be derived from data published in the open literature. Index Doses are set by the Department of Health on a case–by–case basis.

5.13 For most contaminants there is always some intake from the ambient concentrations in food, water, air and other environmental media – usually expressed as a mean daily intake (MDI). The difference between the TDI and the MDI is the maximum intake allowable from soil if the TDI is not to be exceeded – the tolerable daily soil intake or TDSI. The assessment should include a judgement as to the extent of non-identified environmental exposures.

TOX 1–10: Contaminants in soils: collation of toxicological data and intake values for humans for specific substances (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002c)

5.14 For a number of the potential contaminants identified in CLR8, the data available on their human toxicological effects have been reviewed. Using the general approach set out in CLR9, tolerable daily intakes, Index Doses and mean daily intakes are recommended for the first ten of these contaminants and are set out in a series of reports (CLR9 TOX 1–10), as follows:

- TOX 1 Arsenic
- TOX 2 Benzo[*a*]pyrene
- TOX 3 Cadmium
- TOX 4 Chromium
- TOX 5 Inorganic Cyanide
- TOX 6 Lead
- TOX 7 Mercury
- TOX 8 Nickel
- TOX 9 Phenol
- TOX 10 Selenium

Reports on further contaminants are in preparation.

CLR10: The Contaminated Land Exposure Assessment Model (CLEA): technical basis and algorithms (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002d)

5.15 The CLEA model estimates contaminant intake from soil as a function of the contaminant concentration and the potential exposure of adult and children living, working and playing on contaminated land. It derives Soil Guideline Values by comparing the calculated intake with the TDI or Index Dose. The model, its key assumptions, and the underpinning conceptual models for each land-use are described in detail in CLR10.

Table 5.1 Exposure pathways used in the CLEA model.

Pathway No	Description
1	Outdoor ingestion of soil
2	Indoor ingestion of dust
3	Consumption of homegrown vegetables
4	Ingestion of soil attached to vegetables
5	Skin contact with outdoor soil
6	Skin contact with indoor dust
7	Outdoor inhalation of fugitive dust
8	Indoor inhalation of dust
9	Outdoor inhalation of soil vapour
10	Indoor inhalation of soil vapour

5.16 Table 5.1 lists the exposure pathways that are included in the CLEA model. The choice of pathway depends on the conceptual exposure model selected for each land-use and the chemical properties and health effects of a given contaminant.

5.17 Land–use assumptions are described in detail in CLR10. In summary, the CLEA model assumes that land–use falls into one of the following three categories, the first having two sub-categories:

- Residential with and without plant uptake
- Allotments
- Commercial/industrial

5.18 Thus, the Soil Guideline Values derived using CLEA are dependent on exposure in the context of a specified land–use, in accordance with the "suitable for use" approach. As part of the forward programme of developing the CLEA model, a new land–use related to public open space such as parks and playing fields is being developed.

5.19 The fate and transport of chemicals in the soil environment involves physical, chemical and biological processes. More than a century of research has uncovered the principles of how contaminants behave in soil systems, but detailed predictive models of such soil–contaminant systems are still in early development. The CLEA model draws upon the latest scientific understanding in this area, together with knowledge of the behaviour and body characteristics of adults and children, to predict exposure.

5.20 Modelling human exposure to contaminants in soil is a highly complex process. Quantifying risk and exposure gives rise to several different areas of uncertainty and variability. At the highest level, scenario uncertainty is an inevitable consequence of designing a conceptual exposure model that is applicable to a wide range of circumstances. The conceptual models used in CLEA incorporate a precautionary element to account for a reasonable range of possible activities; for example, a substantial minority of people grow and eat their own vegetables, so any generic assessment criteria such as Soil Guideline Values must take these circumstances into account.

5.21 Scenario uncertainty is a big factor in exposure modelling, but other types of uncertainty and variability are also important and can be tackled in different ways. The traditional approach to modelling is deterministic, in that a single value is assigned to each variable. Many of these values are assigned on the basis of either average or conservative measurements and by professional judgement.

5.22 In dealing with parameter uncertainty and variability in a deterministic model, it has been common practice to select values representative of a worst-case exposure scenario and to support this with a sensitivity analysis. This has the assumed comfort of being more protective against an unforeseen situation or risks to sensitive individuals. However, the problem with this approach can be that such choices, however defensible they might be individually, tend to be implausible collectively. If a deterministic model consists of the product of only three exposure parameters chosen at the 90th percentile, then the outcome would represent a 99.9th percentile assessment.

5.23 An alternative to a deterministic approach is the probabilistic exposure model. The probabilistic model replaces some single-value parameters in the exposure assessment with a family of values selected from a defined probability distribution. Each time the model estimates exposure it selects a value from this family. By repeating the assessment, a probabilistic model builds a range of predicted exposures rather than providing a single outcome. This allows the assessor a better understanding of the sensitivity of the assessment to parameter uncertainty and variability and allows more informed judgements about its degree of conservatism. CLEA is a probabilistic exposure model.

SGV 1–10, (Department for Environment, Food and Rural Affairs and the Environment Agency, 2002e)

5.24 Soil Guideline Values have been derived using CLEA for several of the contaminants identified in CLR8. The Soil Guideline Values presented depend on a number of assumptions (for example, relating to the soil conditions, the particular behaviour and type of pollutants, the existence of pathways, the land-use patterns, and the availability of receptors). Assessors of sites need to examine these assumptions and consider their applicability to the site being assessed.

5.25 Assessors should also be aware of other conditions relevant to the use of the Soil Guideline Values, for example, the statistical interpretation of the samples taken or the methods of preparation and analysis of those samples.

5.26 The results for the first ten contaminants are presented in:

- SGV 1 Soil Guideline Values for arsenic contamination
- SGV 2 Soil Guideline Values for benzo[*a*]pyrene contamination
- SGV 3 Soil Guideline Values for cadmium contamination
- SGV 4 Soil Guideline Values for chromium contamination
- SGV 5 Soil Guideline Values for inorganic mercury contamination
- SGV 6 Soil Guideline Values for inorganic cyanide contamination
- SGV 7 Soil Guideline Values for nickel contamination
- SGV 8 Soil Guideline Values for phenol contamination
- SGV 9 Soil Guideline Values for selenium contamination
- SGV 10 Soil Guideline Values for lead contamination

5.27 These reports include information on the background occurrence of the substance, a summary of the toxicity information used to derive the Soil Guideline Value and other specific technical information, and the Soil Guideline Values presented for different land–uses or other key parameters.

5.28 Reports on further contaminants are in preparation.

APPENDIX A

Statistical tests for contaminated soils relative to Soil Guideline Values

This appendix is based upon work by the late Professor Colin Ferguson of Nottingham University.

Introduction

A1 Human health risk assessments of contaminated sites rely on sampling and chemical analysis of soil samples. Advice on developing site sampling strategies is provided in Sampling Strategies for Contaminated Land (Department of the Environment, 1994) and Development of Appropriate Soil Sampling Strategies for Land Contamination (Environment Agency, 2001b).

A2 Once a checked set of chemical data on levels of contaminants in the test area is available, a decision can be made about how these levels compare to the appropriate Soil Guideline Value or a comparable value derived from site-specific study. Whatever values are used for this comparison, it is essential to ensure that the conceptual model and other conditions assumed in the derivation of the Soil Guideline Values are all appropriate to the site under investigation.

A3 If soils were uniformly contaminated at concentration x, acceptance (or otherwise) with respect to a Soil Guideline Value $\underline{G}$ would simply depend on whether x was less than or greater than $\underline{G}$. In reality, contaminant concentrations vary across a site, and the measured mean concentration, derived from a limited number of samples, may not equal the "true" mean; and in any event it will have uncertainty associated with it. Because of this, simple comparisons of the measured mean value with the Soil Guideline Value could be misleading. The approach here is to identify the 95% confidence limits of the measured mean and to compare the upper 95th percentile with the Soil Guideline Value using the mean value test described below.

A4 To determine whether the maximum value in a sample set classifies as an outlier, the maximum value test should be applied. This appendix describes how to conduct statistical tests for each relevant contaminant using the following information collected over a suitable averaging area:

- The arithmetic sample mean
- The standard deviation
- The maximum value

The Mean Value Test

A5 The sample mean value, x, based on only a few samples may be a poor estimate of the true (population) mean. Therefore, a no remedial action decision based on x less than G may not be adequately health protective when x is computed from only a small number of samples. Clearly it is desirable to state with a given level on confidence (say 95th percentile) that the population mean is less than the Soil Guideline Value G.

A6 The necessary calculation involves five simple steps as follows:

(i) calculate the arithmetic sample mean, x.

(ii) calculate the (unbiased) sample standard deviation, s.

(iii) select an appropriate t value from standard tables. Table A 1.1 gives t values for a 95th percentile confidence limit. t values for other confidence limits are given in Table A 1.2. It should be noted that when using Table A 1.2, the number of degrees of freedom (ν) is one less than the number of samples, i.e. for n = 8, $\nu = 7$.

(iv) calculate the upper 95th percentile bound of sample as:

$$U\,S_{95} = \bar{x} + \frac{t.s}{\sqrt{n}}$$

(v) compare the upper bound value, (US_{95}) with the Soil Guideline Value (G). If the upper bound value is less than G, then the mean value test has been passed, and the site may be considered not to present a significant possibility of significant harm to human health in the context of Part IIA. Conversely, if the test is failed, then the assessor should consider whether it is appropriate to take more samples (because the number on which the test has been based is very low), or to make a determination as contaminated land under Part IIA, taking into account the other requirements of the regime such as the presence of a significant pollutant linkage.

A7 The correct value to use for t (for 95th percentile confidence) depends on the sample size n as shown in Table A 1.1. A worked example of application of the mean value test is given in Annex 1.

A8 Some analytical data sets will include samples recorded as below the analytical detection limit (or quantitation limit). The simplest way of handling such data is to include "non detects" but, for calculation purposes, to assign a value equal to the detection limit. Thus if a laboratory reports a substance as <1mg kg^{-1} in soil, a value of 1.0 mg kg^{-1} would be used for calculation.

Table A 1.1 Relationship between sample size (n) and t

n	t	n	t	n	t
-	-	11	1.812	21	1.725
2	6.314	12	1.796	22	1.721
3	2.920	13	1.782	23	1.717
4	2.353	14	1.771	24	1.714
5	2.132	15	1.761	25	1.711
6	2.015	16	1.753	26	1.708
7	1.943	17	1.746	27	1.706
8	1.895	18	1.740	28	1.703
9	1.860	19	1.734	29	1.701
10	1.833	20	1.729	30	1.699

The Maximum Value Test

A9 Values that exceed Soil Guideline Values will invariably warrant some further consideration even when the mean value test has been passed. The problem of acceptance or rejection of maximum values that exceed Soil Guideline Values is not straightforward. This is because there is a need to balance the primary goal of health protection with the recognition that contaminants in soil often have high sampling and analytical variability. This is especially so for contaminants occurring at low concentrations.

A10 In forming a view on whether extra sampling and analysis may be required, a useful question to ask is whether the maximum value in a set of measurements is likely to have come from the same population as the other measurements, or whether it is a statistical outlier.

A11 To make progress with this question it is necessary to assume the form of the underlying distribution; the vast bulk of the relevant literature on outliers relates to an underlying Normal distribution . In the context of chemical analyses of contaminated soils, it is common practice to work with the logarithms of the measured values. This log-transformation usually results in a more or less symmetric distribution which, while not strictly Normal, is usually close enough to allow Normal statistics to be used with some confidence.

A12 Thus the raw measurements x_1, x_2,.....,x_n are first log-transformed ($y_1=\log x_1$ etc); and the sample mean $\bar{y}$ and unbiased sample standard deviation S_y are then calculated from the log transformed values.

A13 An appropriate test is then:

$$T = \frac{y_{max} - \bar{y}}{S_y}$$

If the value of *T* is smaller than some critical value, the maximum value may be accepted (at the prescribed level of confidence) as a member of the underlying population from which the other measurements were drawn. If *T* is greater than the critical value the maximum value is treated as an outlier, which may indicate a localised area of contamination. Of course, the outlier might instead be the result of a measurement or recording error; but in any event it flags up the need for further investigation. A worked example is given in Annex 2.

Annex 1

Worked example of the mean value test

A1.1 Consider, an averaging area in which n = 8 samples are taken with contaminant concentrations as follows:

$x_1 = 80$	$x_5 = 160$
$x_2 = 130$	$x_6 = 90$
$x_3 = 210$	$x_7 = 120$
$x_4 = 350$	$x_8 = 150$

Let the Soil Guideline Value for the contaminant be G = 230.

A.1.2 Compute the following statistics:

(i) arithmetic sample mean $\overline{x} = 161.25$

(ii) unbiased standard deviation $s = 86.59$

(iii) t value from Table A1.1 selected for n=8, t = 1.895

(iv) calculate normalised upper bound (for 95th percentile confidence)

$$US_{95} = \bar{x} + \frac{t.s}{\sqrt{n}}$$

$$= 161.25 + \frac{(1.895).(86.59)}{\sqrt{8}}$$

$$= 219.26$$

Note that the t value used in this calculation is t = 1.895, which is derived from Table A1.1 for single-tailed t tests. For confidence intervals other than the 95 %, refer to Table A1.2.

A.l.3 The upper bound value (US_{95}) of 219 is less than the Soil Guideline Value (G) of 230, and thus it can be concluded that no action is warranted in the averaging area based on the mean value test.

A.l.4 Now consider the situation if only the following 5 samples were available:

x_1 = 80

x_4 = 350

x_5 = 160

x_6 = 90

$$x_7 = 120$$

The arithmetic sample mean, $\overline{x}$ = 160, is slightly smaller than before but the standard deviation (= 110.68) is much larger and the sample size is smaller.

A recalculation gives the upper bound value as 265.5, which is greater than the Soil Guideline Value of 230, and thus the data do not pass the mean value test. In this circumstance, the assessor should consider taking further samples to gain a more representative picture of the site. Alternatively, they may take remedial action where, for example, further sampling is not practicable, or timescales dictate rapid action.

Annex 2

Worked example of the Maximum Value Test

A2.1 The contaminant concentrations listed in paragraph A l.2 are repeated below together with their common logarithms.

i	x_i	$y_i = \log(x_i)$
1	80	1.903
2	130	2.114
3	210	2.322
4	350	2.544
5	160	2.204
6	90	1.954
7	120	2.079
8	150	2.176

A.2.2 The objective is to decide whether the maximum value x_4 = 350 (therefore y_{max} = 2.544) should be treated as an outlier, or whether it can reasonably be considered as coming from the same underlying population as the other samples.

A.2.3 Compute the following statistics:

(i) arithmetic sample mean of *y* values $\bar{y} = 2.162$

(ii) unbiased standard deviation of *y* values $Sy = 0.2046$

(iii) outlier test statistic $T = \frac{y_{max} - \bar{y}}{S_y} = 1.87$

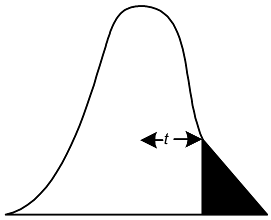
This value, $T = 1.87$, is to be compared with a critical value, T_{crit}, taken from Table A1.3 .

A2.4 The critical values relate to the chance of wrongly classifying a maximum value as an outlier when it is actually from the same underlying population as the other values. In the context of contaminated soil analyses, we are more concerned with wrongly accepting a value, which should properly be treated as an outlier. Therefore 10% critical values are more stringent (i.e. health protective) than 5% critical values, and will usually be most appropriate.

A2.5. The maximum value statistic calculated above ($T = 1.87$) is less than the 10% critical value of 1.91. Therefore it is reasonable to treat the maximum value as belonging to the same underlying distribution as the other values. Note that a maximum value of 370ppm would have been rejected as an outlier using the same test.

A.2.6 It needs to be emphasised that passing an outlier test (i.e. $T < T_{crit}$ does not **prove** that a maximum value is not an outlier possibly representing a (largely undiscovered) area of contamination. It merely demonstrates that the maximum value is reasonably consistent with belonging to the same underlying distribution as the other measurements. As always, statistical tests are an aid to decision making, but are not a substitute for professional judgement.

Table A1.2 – Probability points of the *t* distribution with *v* degrees of freedom



v (degree of freedom) = n-1

Note: this uses degrees of freedom not sample numbers

	Tail area probability, α									
V	0.4	0.25	0.1	0.05	0.025	0.01	0.005	0.0025	0.001	0.0005
1	0.325	1.000	3.078	6.314	12.706	31.821	63.657	127.32	318.31	636.62
2	0.289	0.816	1.886	2.920	4.303	6.965	9.925	14.089	22.326	31.598
3	0.277	0.765	1.638	2.353	3.182	4.541	5.841	7.453	10.213	12.924
4	0.271	0.741	1.533	2.132	2.776	3.747	4.604	5.598	7.173	8.610
5	0.267	0.727	1.476	2.015	2.571	3.365	4.032	4.773	5.893	6.869
6	0.265	0.718	1.440	1.943	2.447	3.143	3.707	4.317	5.208	5.959
7	0.263	0.711	1.415	1.895	2.365	2.998	3.499	4.029	4.785	5.408
8	0.262	0.706	1.397	1.860	2.306	2.896	3.355	3.833	4.501	5.041
9	0.261	0.703	1.383	1.833	2.262	2.821	3.250	3.690	4.297	4.781
10	0.260	0.700	1.372	1.812	2.228	2.764	3.169	3.581	4.144	4.587
11	0.260	0.697	1.363	1.796	2.201	2.718	3.106	3.497	4.025	4.437
12	0.259	0.695	1.356	1.782	2.179	2.681	3.055	3.428	3.930	4.318
13	0.259	0.694	1.350	1.771	2.160	2.650	3.012	3.372	3.852	4.221
14	0.258	0.692	1.345	1.761	2.145	2.624	2.977	3.326	3.787	4.140
15	0.258	0.691	1.341	1.753	2.131	2.602	2.947	3.286	3.733	4.073
16	0.258	0.690	1.337	1.746	2.120	2.583	2.921	3.252	3.686	4.015
17	0.257	0.689	1.333	1.740	2.110	2.567	2.898	3.222	3.646	3.965
18	0.257	0.688	1.330	1.734	2.101	2.552	2.878	3.197	3.610	3.922
19	0.257	0.688	1.328	1.729	2.093	2.539	2.861	3.174	3.579	3.883
20	0.257	0.687	1.325	1.725	2.086	2.528	2.845	3.153	3.552	3.850
21	0.257	0.686	1.323	1.721	2.080	2.518	2.831	3.135	3.527	3.819

22	0.256	0.686	1.321	1.717	2.074	2.508	2.819	3.119	3.505	3.792
23	0.256	0.685	1.319	1.714	2.069	2.500	2.807	3.104	3.485	3.767
24	0.256	0.685	1.318	1.711	2.064	2.492	2.797	3.091	3.467	3.745
25	0.256	0.684	1.316	1.708	2.060	2.485	2.787	3.078	3.450	3.725
26	0.256	0.684	1.315	1.706	2.056	2.479	2.779	3.067	3.435	3.707
27	0.256	0.684	1.314	1.703	2.052	2.473	2.771	3.057	3.421	3.690
28	0.256	0.683	1.313	1.701	2.048	2.467	2.763	3.047	3.408	3.674
29	0.256	0.683	1.311	1.699	2.045	2.462	2.756	3.038	3.396	3.659
30	0.256	0.683	1.310	1.697	2.042	2.457	2.750	3.030	3.385	3.646
40	0.255	0.681	1.303	1.684	2.021	2.423	2.704	2.971	3.307	3.551
60	0.254	0.679	1.296	1.671	2.000	2.390	2.660	2.915	3.232	3.460
120	0.254	0.677	1.289	1.658	1.980	2.358	2.617	2.860	3.160	3.373
∞	0.253	0.674	1.282	1.645	1.960	2.326	2.576	2.807	3.090	3.291

Table A1.3 – Critical Values to test for the presence of outliers.

N	5%	10%
4	1.46	1.42
5	1.67	1.60
6	1.82	1.73
7	1.94	1.83
8	2.03	1.91
9	2.11	1.98
10	2.18	2.04
12	2.29	2.13
14	2.37	2.21
16	2.44	2.28
18	2.50	2.33
20	2.56	2.38

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