OVERVIEW OF INTERNATIONAL SOIL CRITERIA AND DERIVATION OF NUMERIC VALUES

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Introduction

Soil criteria can be broadly defined as numeric values or narrative statements designed to protect the environment and/or human health from detrimental effects of soil contamination. Typically numeric values are used in contaminated site assessment to either instigate action (i.e. further site investigation, remediation) or to provide remediation goals that result in protection of the environment and human health. Soil criteria in the form of (and/or guidance documents for producing) numeric values to indicate the extent of soil contamination have been developed by a number of countries. This has largely been in response to the need to manage existing contaminated sites to reduce the risks of detrimental effects, and as such, criteria reflect the legislative/political framework of contaminated site management of individual countries. Furthermore there are differences in the scientific and philosophical approach to methodologies used to derive numeric values. Landcare Research has been reviewing international soil criteria and we report on aspects of that review focusing on soil criteria produced by the USA, UK, The Netherlands, Canada and Australia.

Background underlying development of soil criteria

In each country the political and legislative background influences the development of soil criteria by defining the purpose of those criteria: e.g. US soil-screening levels are used to indicate sites that require further federal attention under the Comprehensive Environmental Response and Liability Act (CERCLA) and Dutch intervention levels are used to indicate sites for assessment of remediation urgency under the Soil Protection Act (1994). A philosophical decision is also made about whether criteria should be protective of ecological or human receptors. In some cases, one or the other is considered, in other cases both types of receptors are considered. Table I summarises the purpose of available numeric values/protocols, number of numeric values available and the basis for derivation of those numeric values.

Generic numeric values are derived following an agreed procedure and supporting documentation is generally provided to enable derivation of site-specific values using that procedure, if required. However, despite the existence of numerous protocols for deriving numeric values for both human health and the environment, with the exception of the Netherlands surprisingly few generic values have been generated and most of these have focused on protection of human health (see Table I for details).

The Netherlands

The Netherlands has several tiers of numeric values. Intervention values (IV) indicate soil contaminant concentrations that require remediation to land-use-specific remediation values, while target values indicate long-term sustainable soil quality. Intervention values are used to determine remediation urgency of individual sites under the Soil Protection Act (1994). These values are determined by comparing serious risk concentrations determined from ecotoxicological data (SRC_{eco}) with those determined for human exposure (SRC_{human}) and selecting the lowest value as the intervention value. SRC_{eco} is defined as the concentrations at which 50% of tested species or processes in an ecosystem experience adverse effects. SRC_{human} is based on the human-toxicological maximum permissible risk (MPR) level, and back-calculation to calculate the concentration at which the MPR is reached.

Table I. Summary of the purpose of international soil criteria, and availability of numeric targets and protocols or guidance manuals for deriving site-specific values

Country	**Purpose**	**No. of numeric targets, basis***	**Protocols**
Netherlands	Remediation urgency assessment level (IV)	75[1], integrated	De Zwart et al., 1999
	Remediation goal	11[2]	
	Negligible concentrations (NC/TV)	168[3], integrated	
Canada	Remediation goals	24[4], integrated	CCME, 1996a
USA	Screening levels	10[5] Eco 110[6] HH	US EPA, 1991; US EPA, 1996a; US EPA, 1996b; US EPA, 1996c
UK	Intervention values	10[7] HH	Johnson and Cole, 1999[#] Johnson et al., 1999[#] SNIFFER, 2000[#]
Australia	Investigation levels	11[8] Eco 26[8] HH	NEPC, 1999b; NEPC, 1999c; NEPC, 1999d

*integrated – integration of human health and ecotoxicological data, Eco – ecotoxicological data only, HH – human health data only

[#] Protocols developed for the Scottish and Northern Ireland Forum for Environmental Research (SNIFFER) to assist in implementing Part IIA of the Environmental Protection Act – their official standing is unclear

[1]VROM (2000); [2]BEVER (1999), [3]de Bruijn et al. (1999), [4]CCME (1999), [5]US EPA (2000a), [6]US EPA (1996a), [7]DEFRA (2002a and b), [8]NEPC (1999a).

Remediation values were developed in response to a change in policy from remediation of soil to a level “fit for multifunctional use” to “function-orientated and cost-effective remediation” (BEVER, 1999). Numeric remediation goals are available for three land-use types (residential and recreational, non-recreational green areas, built-up and paved areas) and a limited number of contaminants (Table I). Remediation goals for soils for agricultural use or “nature” are required to be determined on a site-specific basis, but no methodology is specified (BEVER, 1999). Further detail of the basis for remediation values is provided by Lijzen et al. (1999).

Target values are based on negligible concentration (NC), which is defined as 1% of the maximum permissible concentration (MPC). The MPC is the concentration at which 95% of species are protected. Derivation of MPC and NC values for water, sediment and soil is based on the assumption that organisms in ecosystems are probably more exposed to compounds in water sediment and soil than are humans, therefore those MPC values are solely based on ecotoxicological data. In contrast humans are considered to be more directly exposed to compounds via air, hence MPC values for air are derived from mammalian inhalation studies or epidemiological studies. When MPCs have been calculated for each environmental compartment, a harmonisation procedure is used to adjust the MPC values (if required) ensuring that transfer of contaminants from one medium to another doesn’t exceed the MPC in that medium (de Bruijn et al., 1999). Background concentrations of contaminants that also occur naturally are taken into consideration using an added-risk approach (Crommentuijn et al., 1997). The calculated NC values were compared to contaminant concentrations in a range of unpolluted soils and adjusted, if necessary, to ensure that the probability of soil from unpolluted areas meeting the target value was a minimum of 95% (VROM, 2000).

Canada

Soil criteria in Canada have been developed within their National Contaminated Site Remediation Program (CCME, 1996b). Numeric values provided in Canadian criteria are used as remediation goals (i.e. “clean-down to” levels, not “pollute up to”) and are based on comparison of calculated concentrations protective of human health or the environment for each designated land-use, and selection of the most protective as their numeric value.

USA

Federal soil criteria was developed in the USA to increase consistency in the screening of Superfund sites to identify sites requiring further federal attention under the CERCLA (US EPA 1996a). Soil screening levels (SSLs) have been developed for protection of human health (US EPA, 1996a) and more recently for protection of the ecosystem (Eco-SSL, US EPA, 2000a). Generic human SSLs are based on a residential-land-use exposure scenario, while Eco-SSLs only apply to sites where terrestrial receptors may be exposed directly or indirectly to contaminated soil. Eco-SSLs are produced for four receptor groups: plants, invertebrates, birds and mammals. Twenty-four contaminants have been identified as priority contaminants for derivation of Eco-SSLs. Additional soil criteria may be derived for individual states, e.g. US EPA 2000b.

UK

Development of soil criteria in the UK is aimed at supporting the application of statutory regimes addressing land contamination, primarily Part IIA of the Environmental Protection Act (1990). Part IIA creates a regime for identifying and remediating contaminated sites, and a recently released circular (Department of Environment, Transport and the Regions (DETR), 2000) provides a definition of contaminated land and statutory guidance for implementation of Part IIA. Specifically, the circular provides for the use of “authoritative and scientifically based guidelines” to simplify the assessment of “significant possibility of significant harm” in relation to soil contamination. A shortlist of potential contaminants was drawn up to identify which were likely to be present on many sites in the UK in sufficient concentrations to cause harm. Some 46 contaminants were selected while an additional 26 individual or groups (i.e. chlorinated solvents, pesticides) of contaminants were excluded (Department for Environment, Food and Rural Affairs (DEFRA), 2002c). While the DETR circular specifically addresses significant harm to ecological systems, guidance documents so far produced by DEFRA have focused on human health aspects. A protocol to assess the potential adverse effects of substances in soil on terrestrial ecosystems has been developed for the Scottish and Northern Ireland Forum for Environmental Research (SNIFFER) by Johnson et al. (1999) to assist in implementing Part IIA of the Act, but it is unclear as to the protocol’s statutory standing.

Australia

Soil criteria in Australia have been developed within National Environmental Protection Measures (NEPM). These measures are statutory instruments aimed at environmental protection, with the degree of specificity in relation to contaminated site management defined by the National Environmental Protection (Assessment of Site Contamination) Measures (NEPC, 1999e).

Methodologies

The general process for deriving numeric values protective of the environment or human health in each country is the same in that a literature review to collate all available information on the contaminant of interest is first conducted. These data are then screened to ensure only data that meet certain quality criteria are used for subsequent derivation. However, methodologies used to derive the numeric values differ between different countries, as do selection criteria of data and toxicological end points. The methods used by different countries are described in more detail below.

Ecotoxicological data

For derivation of numeric values from ecotoxicological data both the type (number of species and end points) and amount of data need to be considered. With regards to standardised end points, typically either the no-observed-effect concentrations (NOECs) or the lowest-observable-effect concentrations (LOECs) are used. Derivation of numeric values based on ecotoxicological data in different countries is based on a hierarchy of methods dependent on data availability. Three levels of methodologies were determined from our review of soil criteria, where level 1 indicates the method preferentially used in each country subject to no data restrictions.

Level 1: Plentiful data

Methods preferentially used by individual countries are generally based on statistical extrapolation procedures, or calculation of the geometric mean of data and have a requirement for a high quantity of high quality data.

The Netherlands

A statistical extrapolation procedure described by Aldenberg and Slob (1993) is used to derive both SRC_{eco} and MPC, provided that at least four NOECs for four different taxonomic groups are available. Ecotoxicological data used are studies based on growth, reproduction, or microbial processes. From these data the concentrations at which 50% (SRC_{eco}) and 5% (MPC) of NOECs are exceeded are determined. This method assumes that data are log-normally distributed.

Canada

Numeric values in Canadian soil criteria are developed using an adaptation of Long and Morgan's (1990) weight-of-evidence approach and require at least 10 data points from three studies including a minimum of two soil invertebrate and two crop/plant data points. These data can include NOECs, LOECs, EC_{50} (concentration at which 50% of the test species exhibit a non-lethal effect in response to exposure) and LC_{50} (concentration at which 50% of the test species die). These data are used to create a frequency distribution from which the 25^{th} percentile is used to define the no-potential-effects range (NPER). Expert judgement is required to prevent values being calculated from biased data, for example bias can be created if greater than 50% of the effects data is LC_{50}s or EC_{50}s, or if greater than 75% of the data is NOECs. In addition, uncertainty factors (1–5) are applied depending on data availability (i.e. whether only the minimum data were available, whether more than 25% of data below the 25^{th} percentile are definitive-effects data).

USA

Eco-SSLs for plants and soil invertebrates are determined from the geometric mean of all toxicity values from the highest preference level. The preference level of a study is determined during the process of review, where studies are scored against nine criteria (maximum score is 2) including toxicological end points and contaminant bioavailability. For studies that score >10/18, a further grouping, on the basis of score, into four levels is undertaken. A minimum of three values are used to calculate an Eco-SSL, with values taken from the next preference level down if insufficient data are available at the highest preference level. Toxicological end points that qualify for the first three levels are EC_{10}, EC_{20}, MATC (maximum acceptable tolerable concentration) or the geometric mean of NOEC and LOEC. No information is provided to indicate whether data from a minimum number of taxa were required.

UK

The statistical extrapolation procedure based on Aldenberg and Slob (1993) is proposed for use in the derivation of numeric values from ecotoxicological data in the UK, provided that a minimum of four data points for four taxa are available (Johnson et al., 1999).

<u>Level 2: Moderate data</u>

The second hierarchy of methods is centered on the application of extrapolation factors to available data, or calculation of geometric means of available data.

The Netherlands

If data are not log-normally distributed or if data for fewer than four taxonomic groups are available, the lowest value of the geometric mean of NOECs and the geometric mean of $L(E)C_{50}/10$ are used to calculate SRC_{eco} (Lijzen et al., 2001). For derivation of MPC, uncertainty factors as indicated in Table II are used (de Bruijn et al., 1999). No minimum data requirements for either method are given.

Canada

A lowest-observable-effect method or a median-effects method is used if insufficient data are available for the weight-of-evidence approach (CCME, 1996b). For both methods at least three studies, including at least one plant and one invertebrate, must be available. The lowest-observable-effect method, which is based on the lowest LOEC, is used preferentially over the median-effect method, which is based on the lowest available EC_{50} or LC_{50}. Uncertainty factors of 5 and 10 are applied to the lowest EC_{50} or LC_{50} respectively. Additionally, uncertainty factors (1–5) may be applied to lowest LOEC, or in addition to the uncertainty factors applied to the EC_{50} and LC_{50}s, depending on data availability (i.e. whether fewer than three taxonomic groups were available, whether the LOEC was taken from an acute or sub-lethal study).

UK

Methods for deriving numeric values in the UK when insufficient data are available for statistical extrapolation methods are based on the application of uncertainty factors, with NOECs as the standardised end point (Table II). Data for at least two to three taxa, including at least one plant and one animal, must be available.

USA

Toxicological end points for data at the lowest preference level in US-Eco-SSL calculations also include EC_{50} values. If only EC_{50} values are available or the EC_{50}>MATC, then the value is divided by 5; if EC_{50}<MATC, then the value is divided by 2. No information is provided to indicate whether data from a minimum number of taxa were required

Table II. Magnitude of uncertainty factors for deriving soil standards in The Netherlands, Canada, USA, UK

Country	Data type	Factor
Netherlands	Lowest NOEC value for chronic toxicity	10*
	Lowest chronic NOEC for a minimum of three reps of microbial mediated processes, earthworms, arthropods or plants	10
	Lowest $L(E)C_{50}$ for a minimum of three reps of microbial mediated processes, earthworms, arthropods or plants	100
	Lowest $E(L)C_{50}$ for acute toxicity	1000
Canada	Lowest LOEC	1–5
	Lowest EC_{50}	5 (1–5)
	Lowest LC_{50}	10 (1–5)
USA	EC_{50}>MATC, only EC_{50} values available	5
	EC_{50}<MATC	2
UK	Chronic NOEC	10
	Chronic LOEC	20
	Lowest EC_{50}	40
	Lowest LC_{50}	150

* this value is compared with that determined from acute $L(E)C_{50}$s. The lowest is selected.

Level 3: Minimal/No data

The Netherlands

The Netherlands is the only country that uses estimation methods for deriving numeric values for soil criteria. Two methods are used: equilibrium partitioning and quantitative structure activity relationships (QSAR). Equilibrium partitioning assumes that soil organisms are primarily exposed to toxicants via the interstitial water, and that soil organisms exhibit similar toxic responses to aquatic organisms. Values for soil organisms are related to relevant aquatic toxicity values (MPC for water or SRC for water) by the soil-water partitioning coefficient. QSARs are based on the correlation between toxicity of a certain compound and one or more structural parameters of the compounds (e.g. K_{ow}) through linear or non-linear regression, and can only be established for compounds with a common mode of toxic action. QSARs are used to estimate toxicity of a compound for which no toxicity data are available.

Australia

While a draft document describing the methodology for deriving ecological impact levels of soil contamination was published (Environment Australia, 1997) and reviewed internationally (Environmental Protection Agency, 1997), there is currently no guidance on what methodology will be followed to derive generic values for protection of the environment from soil contamination. Existing interim ecological investigation levels (EIL) have been collated from ANZECC B-levels and soil survey data from four Australian cities. The ANZECC B-levels used as interim EIL originate from Environment Canada (1988) and Richardson (1985).

Wildlife

Consideration of the effects of contaminated soil on wildlife in the derivation of numeric values for protection of the environment is largely based on ingestion of contaminated soil or contaminated food. Secondary poisoning effects are considered in the derivation of

MPC_{soil} in The Netherlands, although wildlife is not considered in the derivation of SRC_{eco}. Ingestion of contaminated soil and food is considered for grazing livestock and herbivorous wildlife in Canadian Guidelines, and US Eco-SSL values for birds and mammals are based on ingestion of contaminated soil and food.

Human health

Derivation of human-health numeric targets largely focuses on standard exposure scenarios for designated land uses. Those designated land uses differ for individual countries. The toxicological basis for the derivation of human-health values is either determination of tolerable daily intakes (TDI) for contaminants that have a threshold concentration that needs to be exceeded for toxic effects to be manifested (threshold contaminants); or individual excess cancer risk for contaminants that have the potential to cause detrimental effects at all concentrations (non-threshold contaminants).

The Netherlands

Derivation of numeric values protective of human health are only undertaken for determination of SRC_{human} and MPC_{air}. The CSoil model is used to calculate SRC_{human} assuming residential-land-use and realistic exposure scenarios, based on average situation and average human behaviour (Lijzen et al., 2001). SRC_{human} is based on calculation of the MPR, which is either the threshold that needs to be exceeded for toxic effects to be manifested or an excess lifetime cancer risk of 10^{-4}, for individual compounds and back-calculation using CSoil to determine what soil concentration would yield that exposure. The values determined are averages over a lifetime of exposure and don't take into consideration background concentrations. The main exposure pathways in CSoil that are considered to cover at least 90% of intake are ingestion of soil particles, volatile compounds in indoor air, and consumption of contaminated crops (Lijzen et al., 2001).

Canada

Numeric values protective of human health are derived from standardised equations for soil ingestion, soil dermal contact, and inhalation, based on exposure scenarios for agricultural, residential, commercial and industrial land-use (CCME, 1996b). For threshold compounds these equations are used to determine soil concentrations at which 20% of the residual tolerable daily intake (RTDI) would be exceeded. The RTDI is the difference between the tolerable daily intake and the estimated daily intake from all background sources. The RTDI is apportioned evenly to each of five primary media - air, water, soil, food, and consumer products (CCME, 1996b). For threshold compounds, exposure is averaged over, and TDIs measured against the most sensitive life-stage, which is generally the "toddler" stage (6 mths to 4 yrs). For non-threshold compounds an increased cancer risk of 10^{-6} over a lifetime is used instead of RTDI. A second step in the derivation of numeric values protective of human health is a check on exposure through four indirect exposure pathways. For residential land-use these pathways are ingestion via groundwater and infiltration of contaminants into indoor air.

USA

Human-health SSLs are risk-based concentrations determined using standardised equations combining exposure assumptions and EPA toxicity data for ingestion of contaminated soil and groundwater, and inhalation. The models and assumptions used to derive SSLs are consistent with Superfund's concept of reasonable maximum exposure (RME) in a residential setting (UE EPA 1996a). A default area of 0.5 acre is used to generate generic SSLs using the standardised equations. For non-threshold contaminants, the toxicity criterion used to define an acceptable level of contamination in the soil is an individual excess cancer risk of 10^{-6}, and a hazard quotient of 1 is used for threshold contaminants. Exposures are typically averaged over a lifetime for non-threshold contaminants. For threshold contaminants exposure is based on childhood (6 yrs) for direct ingestion of soil and 30 yrs for inhalation. The generic values are considered to be conservative, and site-specific information should be used to derive appropriate SSLs.

UK

The CLEA model is used in the UK to evaluate the average daily intake of a contaminant for a given initial soil concentration. The primary pathways of exposure considered are soil ingestion, inhalation and dermal contact (DEFRA, 2002d). For threshold compounds this daily intake cannot exceed the tolerable daily soil intake (TDSI), which is the difference between TDI and the average daily intake from all background sources (MDI). For non-threshold contaminants an index dose, which is set specifically for exposures from soil, cannot be exceeded.

Australia

General guidance on the conduct of human-health risk assessment is available (NEPC, 1999b) and human-health investigation levels for a range of land uses have been based on exposure settings described in NEPC (1999f). However, limited information on the parameters used for determination of these numeric values is available (NEPC, 1999d).

Use of soil parameters in derivation of numeric targets

Soil properties influence the toxicity of contaminants to soil organisms, and the transport of those contaminants from the soil to other media. However, the extent to which soil parameters are considered in the derivation of values protective of the environment is variable. Dutch values are based on a standard soil (25% clay and 10% organic matter) and provide equations allowing for extrapolation to other soil types (De Bruijn et al., 1999). Canadian guidelines do not consider the influence of soil parameters on ecotoxicological data collected from the literature (CCME, 1997) while the US Eco-SSL values are derived from toxicity values in studies that had soil pH 4.0 and 8.5 and organic matter <10% (US EPA 2000a). In the UK it is recommended that normalisation of toxicity end points for organic compounds is conducted based on soil organic matter content. No normalisation of metals is recommended due to the absence of data specific to the UK (Johnson et al., 1999).

Soil parameters are used to a greater extent in the derivation of numeric values protective of human health. Canadian guidelines consider the influence of soil properties on the transport to groundwater and volatilisation, and the subsequent effects of exposure through those pathways on humans. Standard soils are used in models to derive generic human-health criteria, while site-specific data can be used to derive site-specific values.

Science underlying derivation of numeric values

There is considerable debate within the scientific community regarding the relevance of certain toxicological parameters, such as NOECs, and LOECs (e.g. Power and McCarty, 1997; Chapman et al. 1998) and extrapolation methods (e.g. Forbes and Forbes 1993) for determining protective values. Additionally, validation of methods to derive numeric values, and the protectiveness of those numeric values, has rarely been conducted. An exception to this is validation of the values determined for zinc using the statistical extrapolation method of Aldenberg and Slob (Posthuma et al., 1998). However, the debate surrounding validity and application of rigorous methods for the derivation of numeric values, such as statistical extrapolation methods, is largely irrelevant for the derivation of numeric values for the soil environment as there is typically insufficient ecotoxicological data to use those methods or even to develop numeric values for a wide selection of compounds using less rigorous methods (Tables I and III). Furthermore there is uncertainty surrounding the value of some of the basic physico-chemical parameters, such as K_{ow} (e.g. Pontolillo and Eganhouse, 2001), that are used in calculation of values protective of human health and transport of contaminants. Revision of physico-chemical parameters used in calculation of Dutch numeric values resulted in over two-fold increases or decreases in MPR and SRC_{human} (Lijzen et al., 2001; Otte et al., 2001). Serious consideration needs to be given to the use of numeric values and the derivation of numeric values to protect the environment based on limited data.

Table III. Methods used to derive numeric values based on ecotoxicological data in The Netherlands and Canada.

		Level 1	**Level 2**	**Level 3**	**None/ provisional**	**Total (n)**
Dutch IV*	Metals	71%	15%	0	14%	16
	Organics	1%	38%	24%	37%	106
Dutch MPC**	Metals	28%	22%	50%		18
	Organics	0	33%	64%	3%	150
Canada#	Metals	90%			10%	11
	Organics	39%			61%	13

*based on revised intervention values (Lijzen et al., 2000).
** from Sijm et al. (2001)
# these data are based on CCME (1997), but insufficient information is available to ascertain whether these values were calculated using level 1 or level 2 methods.

Application of soil criteria in New Zealand

While a multitude of numeric values and guidance documents to produce numeric values are available internationally, these documents have been produced within the context of the policy and legislative frameworks of individual countries. Therefore, the purpose and application of numeric targets/guidance documents within New Zealand need to be considered within our political and legislative environment. For example, the reason for deriving numeric targets needs to be clearly identified: Do those values represent action levels for site remediation or remediation goals? What weight should be placed on protecting the ecosystem versus human health? With respect to human health, exposure scenarios reflective of New Zealand land-use need to be determined. Similarly, protocols for soil sampling and standard methods of analysis need to be developed to ensure that initial site assessments are consistent and provide data required for any subsequent derivation of site-specific values. Finally, cost restraints on conducting risk assessments need to be recognised and taken into account; there is a need to produce generic values, in addition to protocols for deriving site-specific values.

Abbreviations:

CCME – Canadian Council of Ministers for the Environment
CERCLA – Comprehensive Environmental Response and Liability Act (USA)
DEFRA – Department for Environment, Food and Rural Affairs (UK)
DETR – Department for Environment, Transport and the Regions (UK)

EC50 – concentration at which 50% of test organisms exhibit a sub-lethal effect in response to exposure
EIL – ecological investigation level (Aus)
IV – intervention value (Dutch)
LC50 – concentration at which 50% of test organisms die
LOEC – lowest observed effect concentration
MATC – maximum acceptable tolerable concentration
MDI – daily intake of contaminants from background sources (UK)
MPC – maximum permissible concentrations (Dutch)
NC – negligible concentrations (Dutch)
NEPC – National Environment Protection Council (Aus)
NEPM – National environmental protection measures (Aus)
NOEC – no observed effect concentration
NPER – no potential effects range (Canada)
QSAR – quantitative structure activity relationships
RTDI – residual tolerable daily intake (Canada)
RME – reasonable maximum exposure (USA)
SRC_{eco} – serious risk concentration for ecological systems (Dutch)
SRC_{human} – serious risk concentration for human health (Dutch)
SSL – soil screening level (USA)
TDI – tolerable daily intake
TDSI – tolerable daily soil intake (UK)

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