DEVELOPING SOIL GUIDELINE VALUES FOR THE PROTECTION OF SOIL BIOTA IN NEW ZEALAND

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To assist in managing soil quality, different policy and regulatory approaches have been implemented in recent years. From an agricultural perspective the National Cadmium Management Strategy was released in February 2011 and includes a Tiered Fertiliser Management System to assist in reducing cadmium accumulation on agricultural land over time; from a contaminated land perspective, the *National Environmental Standard for Assessing and Managing Contaminants in Soil to Protect Human Health* (the NES) came into effect on 1 January 2012. Additionally, guidelines are currently being developed for the management of the disposal of solid waste to land, and the beneficial use of organic waste (updating the Biosolids guidelines) that also are designed to prevent the negative impact of contaminants on the environment.

Under the Resource Management Act, regional councils and unitary authorities have responsibilities for soil quality and land management to safeguard the life-supporting capacity of soil and ecosystems, and ensure any adverse effects on the environment are avoided or mitigated. Fundamental to ensuring regional councils can fulfill these responsibilities is the need for a clear understanding of how hazardous substances potentially affect soil organisms (microbes, macrofauna and plants), and higher organisms (livestock, wildlife). Soil guideline values developed to protect soil biota (Eco-SGVs) provide a useful means to readily assess potential environmental impact. Further, the soil Cd concentrations currently used as trigger values in the TFMS are from a variety of sources, although the development of risk-based soil guideline values specific to New Zealand, in line with a review of the strategy in 2017, is identified as part of the Governance work programme (MAF 2011). New Zealand derived cadmium Eco-SGVs provide one such risk-based soil guideline value.

However, a consistent methodology for deriving such criteria for use in New Zealand has not been agreed. A two-year Envirolink project commenced in July 2014 aimed at helping regional councils develop soil guideline values for the protection of ecological receptors (Eco-SGVs). As Eco-SGVs can differ in their level of protection depending on their context, feedback will be sought from industry and other stakeholders regarding their application and to achieve agreement on the derivation methodology. This paper provides an update on the status of this ongoing project.

Introduction

Soil guideline values developed to protect soil biota (Eco-SGVs) provide a useful means to readily assess potential environmental impact. Some soil guideline values already exist, e.g. within the Timber Treatment Guidelines (MfE 2011) or Biosolids Guidelines (NZWWA 2003), but these are for a limited number of contaminants and are based on inconsistent methodologies. The absence of national Eco-SGVs has resulted in inconsistency and a lack of clarity around protection of ecological receptors in soil, and a lack of focus on ensuring this protection in territorial and regional/unitary council functions.

The 'Background concentrations and soil guideline values for the protection of ecological receptors' Envirolink Tools Project (Eco-SGV tools project) aims to:

- Develop nationally agreed methodologies for determining background soil concentrations of naturally occurring elements, and ecological soil guideline values (Eco-SGVs) for the protection of soil biota, such as soil microbes, plants and soil invertebrates
- Use existing data to determine background concentrations and Eco-SGVs for multiple land-use scenarios
- Develop clear guidance to follow in applying Eco-SGVs for different purposes to ensure they are applied correctly.
- Identify requirements for a database that enables ongoing input of trace element concentrations and links to existing soil quality databases (e.g. SINDI https://sindi.landcareresearch.co.nz/

In essence this project aims to develop Eco-SGVs for the most commonly encountered contaminants, and establish agreed methods for derivation such that values can subsequently be developed for other contaminants of concern as needed. Determination of background soil concentrations are included within this project as methodologies for deriving Eco-SGVs may include their use, or they may be used as criteria to ensuring environmental protection (e.g. cleanfill criteria).

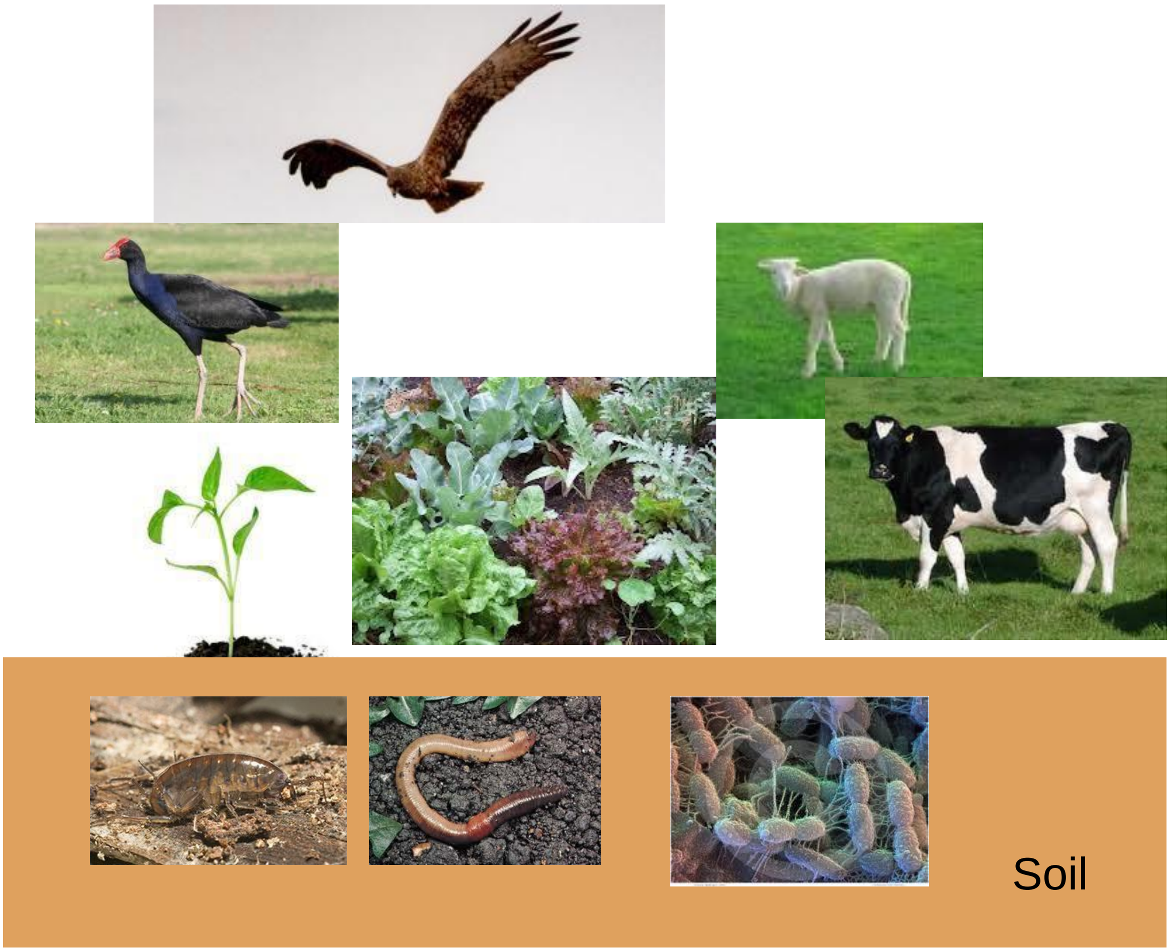

Figure 1 Receptors to be considered in the development of ecological soil guideline values.

Background

A meeting of the advisory group (representatives from the Regional Council Contaminated Land and Waste and Land monitoring forums, Land Managers Group, the Ministry for the Environment and the Ministry for Primary Industries) for the Eco-SGV tools project confirmed the range of receptors to be considered in the development of Eco-SGVs (Figure 2), and the contaminants for which Eco-SGV will be derived from this project (Table 1). Contaminants selected include the most common contaminants, and as well as contaminants for which toxicity to livestock (F) or bioaccumulation in wildlife (DDT) needs also to be considered.

Table 1 Priority contaminants for the development of Eco-SGVs*

Inorganic contaminants	**Organic compounds**
Arsenic, copper, cadmium, chromium, fluoride, lead, zinc	DDT, total petroleum hydrocarbon (TPH), polycyclic aromatic hydrocarbons(PAH)

*If sufficient resources allow, Eco-SGVs will be developed for additional contaminants.

Application of Eco-SGVs and background concentrations of trace elements and related projects

Eco-SGVs and background soil concentrations are typically used for two key purposes:

- Contaminated land management: identifying contaminated land, determining remediation objectives
- Protecting soil quality:• Long-term soil protection where products that may contain contaminants are applied to land, e.g. fertiliser application, animal manures, biosolids
- Long-term soil protection from waste disposal, e.g. cleanfills, managed fills

Management of contaminated land is a key application for Eco-SGVs in New Zealand and another is protection of ecological receptors in soil to ensure soil quality, for example for cleanfills, managed fills and application of biosolids to land. Cleanfills and managed fills provide a useful means to dispose of uncontaminated or minimally contaminated material, and reduce the amount of material potentially disposed of to landfill. Similarly, the application of biosolids to land provides for their beneficial use, as well as reducing the amount of material disposed of to landfill. However, there is a statutory requirement to ensure concentrations of any potential contaminants in the clean/managed fill or biosolids do not result in detrimental effects on soil biota (i.e. to ensure any adverse effects on the environment are avoided or mitigated).

A key important difference in developing Eco-SGVs and developing criteria for cleanfills, managed fills, application of biosolids to land etc. is that for the latter all potential impacts – i.e. to human health, leaching to groundwater, protection of soil biota – should be considered. For some contaminants, human health impacts or leaching to groundwater may pose a greater potential risk than the impact on ecological receptors, and be the defining point for setting relevant criteria.

Related projects

There are two related projects that are currently being undertaken ('Beneficial use of organic waste') or nearing completion ('Land disposal guidelines') for which the determination of background soil concentrations and development of Eco-SGVs have relevance. As consistency in updated soil limits and Eco-SGVs is required to avoid confusion among regulators and industry, it is intended that the Tools Project complements, rather than conflicts with this other work. Specifically, it is anticipated that the *application* of waste criteria/soil limits is specified within the particular guidelines, but that the *methodology* or information (e.g. background soil concentrations) developed in this Tools Project is used to inform the criteria or limit-setting where these relate to background soil concentrations or protection of ecological receptors.

This section provides a brief overview of the current status of the two projects, and identifies the relationship between the information generated in the Tools Project and waste acceptance criteria/soil limits used by these projects.

Land disposal guidelines

The Land Disposal Technical Guidelines were released for public consultation in July 2013 (WasteMINZ 2013) and currently a final draft version of the guidelines is with the Ministry for the Environment for review, following which they will be finalised (Paul Evans, CEO WasteMINZ, pers. comm.). The following is taken from a near-final version provided by Paul Evans (Wasteminz).

The Land Disposal Technical Guidelines consider landfills classified into four types:

- Class 4 Landfill – Cleanfill
- Class 3 Landfill – Managed/Controlled Fill
- Class 2 Landfill – C&D Landfill or Industrial Waste Landfill
- Class 1 Landfill – Municipal Solid Waste Landfill or Industrial Waste Landfill

Of most relevance to the Tools Project are Classes 3 and 4, as no liners are required for these landfills, enabling direct contact of the surrounding soil with the landfilled materials. Class 4 landfills accept materials such as virgin excavated natural materials (VENM), which include soils, clays, gravels and rocks, and limited amounts of inert manufactured materials (e.g. concrete, brick, tiles) and incidental or attached biodegradable materials (e.g. vegetation). The definition of cleanfill states that "when discharged to the environment clean fill material will not have a detectable effect relative to the background", and regional background concentrations are the specified waste acceptance limits to be used (section 5). Appendix C provides an overview of the development of waste acceptance criteria, which includes consideration of leaching potential, human health exposure, exposure of ecological receptors and Appendix G provides class 4 waste acceptance criteria – as examples of regional background concentrations for key inorganic elements, and specified criteria for selected organic contaminants.

It should also be noted that approaches used by regional councils to date for cleanfill criteria have been variable (e.g. either based on background concentrations alone or a combination of background concentrations and Eco-SGVs).

A Class 3 landfill accepts managed/controlled fill materials, which are considered to be predominantly cleanfill materials but also other inert materials and soils with chemical contaminants in excess of local background concentrations, but with specified maximum total concentrations (section 5). Appendix C identifies the exposure pathways, relevant criteria for each pathway (value and source), and the limiting exposure pathway. The final criteria are provided in Appendix F and are a mix of criteria for the protection of human health, ecological receptors, and aquatic receptors.

Guidelines on the beneficial use of organic waste
A guideline to facilitate the beneficial use of organic waste – which includes updating of the soil limits to protect human health and the environment in the Biosolids Guidelines (NZWWA 2003) – is currently being developed through industry and research groups (NZWater, WasteMINZ, Centre for Integrated Biowaste Research (CIBR), and the Land Treatment Collective (LTC)) with an advisory group including Ministry for the Environment, Ministry for Primary Industries and Ministry of Health. This project is currently in progress and review of contaminants of concern (metals, pathogens and organic contaminants) for the application of organic wastes to land has been undertaken to identify the specific contaminants of concern, and relevant existing national and international soil guideline values. The next step is to produce a draft guideline for the project's advisory group (N. Walmsly, NZWater, pers. comm.).

Methodologies for developing Eco-SGVs

Background to the proposed approach for developing Eco-SGVs
Comprehensive review of international approaches to developing soil guideline values for the protection of ecological receptors has been provided in Cavanagh & O'Halloran (2006) and MPI (2012). The latter also provides recommendations for a proposed approach for developing Eco-SGV for cadmium that are developed further in Cavanagh (2014). A series of articles in the July 2014 issue of *Integrated Environmental Assessment and Monitoring*, which arose out of a US EPA workshop on the development of site-specific soil guideline values for metals, provide a more recent review of international approaches (e.g. Greenberg et al 2014). These articles note the similarity between Australian methods for deriving Ecological Investigation Levels (EILs) and EU for assessing risks under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) process, and endorse the approach adopted as well as noting the opportunity to use the toxicity data compiled by Australian and EU agencies (Checkai et al 2014, Greenberg et al 2014). This in turn provides support for the recommendations made in MPI (2012) for adopting the Australian methodology for deriving ecological investigation levels (EILs) (Heemsbergen et al. 2009; NEPC 2013a), adapted as needed to suit a New Zealand context (MPI 2012). The rationale for this recommendation was that it would ensure consistency between Australian and New Zealand approaches for deriving soil guideline values for the protection of terrestrial ecological receptors, and also with the Australian and New Zealand Water Quality guidelines (ANZECC/ARMCANZ 2000) (MPI 2012).

The specific attributes of the Australian and EU methodology that are seen as valuable are the incorporation of soil characteristics into the development of the Eco-SGV, and the use of the 'added-risk ' approach for developing Eco-SGV for metals (Checkai et al 2014, Greenberg 2014). The incorporation of soil characteristics in making the toxicity assessment includes normalisation to a standard soil, accounting for ageing etc. The ability to include these parameters is dependent on the availability of data. The 'added- risk' approach enables the background concentration of soils to be taken into account, and can allow for regional variation. However, it is noted that within the EU the added- risk approach has been variably used in the Risk Assessment conducted under the REACH programme. Notably the added risk approach is used in the Zinc RAR (EC2008a), but not in the Copper RAR (EC 2008b). The reservation in use appear to primarily stem from the view of Scientific committee on health and environmental risks, which reviews many of the risk assessment reports, that the absence of region-wide background soil concentrations that can be used limits the ability to use the added-risk approach (e.g. SCHER 2009).

The 'added risk approach' considers that the availability of the background concentrations of a contaminant is zero or sufficiently close that it makes no practical difference, and that it is the added anthropogenic amounts that are of primary consideration for toxicity considerations (e.g. Crommentuijn et al. 1997).

Proposed approach

A summary of the proposed approach is provided below with further details shown in the following sections. Briefly, the approach entails:

- Collation and screening the data
- Standardisation of the toxicity data
- Incorporation of an ageing/leaching factor for aged contaminants
- Calculation of an added contaminant limit (ACL) by either the species sensitivity distribution (SSD) or assessment factor (AF) approach, depending on the toxicity data
- Normalisation of the toxicity data to a New Zealand reference soil (only if the SSD approach is used to calculate the ACL)
- pH – 5.5, Clay – 23%, CEC 21 cmol/kg, Organic carbon – 5.5%.
- Accounting for secondary poisoning
- Calculation of the ambient background concentration (ABC) of the contaminant in the soil
- Calculation of the SGV by summing the ACL and ABC values: SGV = ABC + ACL.

Cavanagh (2014) also provided an assessment of the status of the steps required to develop Eco-SGVs for cadmium, which is helpful to inform the development of Eco- SGVs for other contaminants (Table 2).

Table 2 Summary of status of New Zealand knowledge in relation to the steps identified in NEPC (2011a) to derive ecological investigation levels for cadmium.

Step	New Zealand status
Collation and screening the data	Cavanagh and O'Halloran (2006) collated an extensive amount of international toxicity data that can be built upon for further derivations.
Standardisation of the toxicity data	The toxicity endpoint data used in NEPC (2011a) are EC30 or LOEC values – the data used by Cavanagh and O'Halloran (2006) were NOEC or EC10 data, which are more conservative. Standardisation of data is required. In terms of gaining consensus on the adopted methodology, it would be useful to present Eco-SGVs based on both endpoints.

Incorporation of an ageing/leaching factor (ALF)	On the basis of toxicity measures in a variety of European field and freshly spiked soils, Smolders et al. (2009) determined an ALF for Cd^{2+} of 1, i.e. ageing did not significantly reduce the toxicity compared with toxicity arising from freshly spiked soils. Thus as a starting point it is recommended that an ageing/leaching factor of 1 is used for deriving Cd SGVs, unless data showing an influence of ageing in New Zealand soils become available.
Calculation of an added contaminant limit (ACL) by either the species sensitivity distribution (SSD) or assessment factor (AF) approach, depending on the toxicity data	Cavanagh and O'Halloran (2006) found sufficient international data to use an SSD approach, thus an SSD approach is likely able to be used with the revised dataset.
Normalisation of the toxicity data to the Australian reference soil (only if the SSD approach is used to calculate the ACL) ph – 6; Clay – 10%; CEC – 10 cmol/kg; organic carbon – 1%	Based on values in the National Soils Database held by Landcare Research, a potential New Zealand reference soil based on 'typical' values would be: pH – 5.5, Clay – 23%, CEC 21 cmol/kg, Organic carbon – 5.5%.
Accounting for secondary poisoning	Required
Calculation of the ambient background concentration (ABC) of the contaminant in the soil	NEPC (2011a) references some Australian studies, including Hamon et al. (2004) who developed equations for background concentrations based on iron content. This did not include Cd. McDowell et al. (2013) provide a relationship to determine background concentrations of soil Cd., There is also a proposed project that may extend the range of soils examined by McDowell et al. (2013) that could also be used to determine background soil concentrations.
Calculation of the SGV by summing the ACL and ABC values: SGV = ABC + ACL	

One of the most effective means of taking different applications of Eco-SGVs into account is to develop Eco-SGVs for different land-uses, which take into account different levels of protection suitable for a given land-use. A wider range of land-uses were considered in the development of the Australian EILs (Table 3) than was finally adopted (NEPC 2013b); notably EILs for agricultural land-use were not developed. A summary of the level of protection for ecological receptors for different landuses, taking into account whether the contaminant in question biomagnifies, is provided in Table 3. This is proposed as the starting point for discussion on the level of protection of different land- uses in New Zealand.

Table 3 Percentage of species and soil processes to be protected for different land uses (Heemsbergen et al. 2009)

Land use	Standard % protection	Biomagnification protection[1] (%)
Urban residential	80	85[2]
Public open space	80	85[2]

Commercial	60	65[3]
Industrial	60	65[3]
Agricultural	95[4] and 80[5]	98[3,5] and 85[3,5]
National parks	99	99

[1]If a contaminant meets criteria for biomagnification, [2]If surface area exceeds 250 m^2; [3]If surface area exceeds 1000 m^2, [4]Agricultural crops, [5]For soil processes and terrestrial fauna.

For agricultural land use, only agricultural species are proposed for inclusion among the plant data and a high level of protection (95%) is provided for crop and grass species. Soil processes and soil invertebrates are considered highly important to ensure nutrient cycling to sustain crop species, although tillage and the use of pesticides/herbicides make it unrealistic to protect 95% of soil processes and soil invertebrates and therefore only 80% of these are nominally protected. Essentially there are four levels of protection:

- National parks and areas of high conservation value
- Urban residential and open public spaces
- Commercial and industrial
- Agricultural land

Background soil concentrations

The final step in developing Eco-SGVs is the addition of the derived ACL to background concentration. Cavanagh (2013) provides recommendations for a nationally consistent approach to determining background soils concentrations across New Zealand. In particular, it is noted that spatial tools are increasingly used international to determine background soils information (e.g. Lado et al. 2008; Cave et al. 2012) or to utilise background concentration information (e.g. Sheppard et al. 2009). Often geostatistical analyses are undertaken and used to define relevant 'domains' or groupings where background concentrations are similar. Such tools enable the extrapolation of collected data to areas where data have not been collected. The current project undertakes analysis of existing data available for New Zealand to identify whether key factors influencing trace elements can be identified, thus enabling "domains" of expected concentration range to be determined (Ander et al 2011).

Methodology

Trace element concentrations have been obtained primarily from regional council soil quality monitoring programme or specific project to determine background concentrations in different regions. In addition, data for surface soils was obtained from the National Soils Database. These data have been compiled into a database, and GPS locations used to extract additional data on selected soil properties from a range of databases. Data from the most recent sampling of a given location was used for subsequent analyses. The databases used are:

- **LRIS** - The Land Resources information System (LRIS) (http://lris.scinfo.org.nz/) is a means for the public to access environmental data held by Landcare Research. Data layers available include NZLRI fundamental data soil layers (FSLs), vegetation data layers, and land-cover database. The NZLRI (FSL) is a spatial database that describes land on the basis of five characteristics including rock type.

- **S-Map** (http://smap.landcareresearch.co.nz/home) is a spatial database for New Zealand soils that has been designed to provide quantitative soil information for modellers and to provide the best-available soil data for use by land managers and policy analysts (Lilburne et al. 2012). S-Map includes linkages to the National Soils Database and Q-Map, a geological spatial database developed by GNS (see below). S-Map contains information on parent material, rock class of fines (<2 mm) for the defined soil siblings, which could be of use in explaining geochemical variations in different soil types
- **Q-Map** (http://www.gns.cri.nz/Home/Our-Science/Earth-Science/Regional-Geology/Geological-Maps/1-250-000-Geological-Map-of-New-Zealand-QMAP) is a national spatial database containing geological information and was developed by GNS over the period 1993–2012. It provides geological maps at 1:250 000 scale across New Zealand.

A summary of the specific parameters extracted from the above databases to determine their relationship to the variation in trace element concentrations is provided in Table 11.

Table 4 Summary of specific parameters of interest to explain variations in background concentrations in existing spatial databases

LRIS	S-Map	Q-Map
Rock type[1]	Rock type of fines	Rock group, rock class

[1]Rock type groupings provided in the FSL are grouped up into: ultramafics, igneous, surficial, weak sedimentary rock, strong sedimentary rock, and metamorphic rocks.

Statistical analyses

Statistical analyses were undertaken using R version 3.0.2. Data from all land-uses was initially used and linear regression models were developed for each element as a function of the land use, soil order, plus various combinations of the top rock, Qmap, and Smap variables. In these models, we select one of the top rock, Qmap, and Smap variables. The various factors are additive, so the effect of land use, soil order, and top rock or Qmap or Smap variables can be considered separately. An ideal model would explain all of the variation of log-concentration in terms of various explanatory factors, and models might be expected to be "better" if they explain a higher proportion of the variation. Thus, the adjusted R-squared value is relevant in the comparison between models and starts to indicate which factors may be suitable explanatory variables. For a given element, RockGroup (Q-Map) or Rock Class of fines (S-Map) typically provide the greatest explanatory power (Table 5). Given the smaller number of samples in the S-map the results need to be read with some caution. Further investigation will be undertaken to establish whether this relationship is stronger if data from locations that do not appear to have been influenced by land-use (Background, Forestry).

In addition to the further analyses of existing data, the next phase of analysis will include analysis of data being collected by GNS Science. Over 400 samples have been collected at 2 depths at a spacing of an 8km grid and will be analysed for all major and trace elements using ICPMS and XRF (Rattenbury et al 2014). These data will be used test the strength of any observed relationships identified from the previous analyses, or determine whether any new parameters provide greater predictive power.

Table 5 Adjusted R-squared and number of cases is shown for each element, and for each source of the parent rock factor**.**

Element	Adj. R-squared	Num. samples	Parent rock factor
Cu	0.3009209	768	TopRock
Cu	0.3034848	801	RockGroup (Qmap)
Cu	0.297089	801	RockClass (Qmap)
Cu	0.3023315	440	RockClassFine (Smap)
Zn	0.291185	785	TopRock
Zn	0.2936048	818	RockGroup (Qmap)
Zn	0.2753764	818	RockClass (Qmap)
Zn	0.4179415	440	RockClassFine (Smap)
Cd	0.6022354	786	TopRock
Cd	0.6246914	819	RockGroup (Qmap)
Cd	0.5988751	819	RockClass (Qmap)
Cd	0.5980714	440	RockClassFine (Smap)
Pb	0.341018	768	TopRock
Pb	0.3818485	801	RockGroup (Qmap)
Pb	0.3428906	801	RockClass (Qmap)
Pb	0.4596979	440	RockClassFine (Smap)
Cr	0.5041293	767	TopRock
Cr	0.5346701	800	RockGroup (Qmap)
Cr	0.4800833	800	RockClass (Qmap)
Cr	0.7015988	440	RockClassFine (Smap)

Summary and next steps

This paper has provided an overview of the proposed approach for developing Eco-SGVs and determining background soil concentrations. Within the proposed methodology, different decisions can be made about the choice of toxicological data used and the level of protection afforded by the Eco-SGVs that ultimately determines the final "number" that is developed (Figure 1). These decisions are more a matter of policy and consensus rather than science, and should take into account the intended application of the Eco- SGVs. To assist in the development of Eco-SGVs, a series of workshops on the methodology and application of Eco-SGVs will be held with various stakeholder groups including regional councils, organic waste sector, and contaminated land practitioners. To assist with workshop discussions, Eco-SGVs for copper and zinc will be developed an illustration of the effect of the decisions on the toxicological data and level of protection make to the final "number".

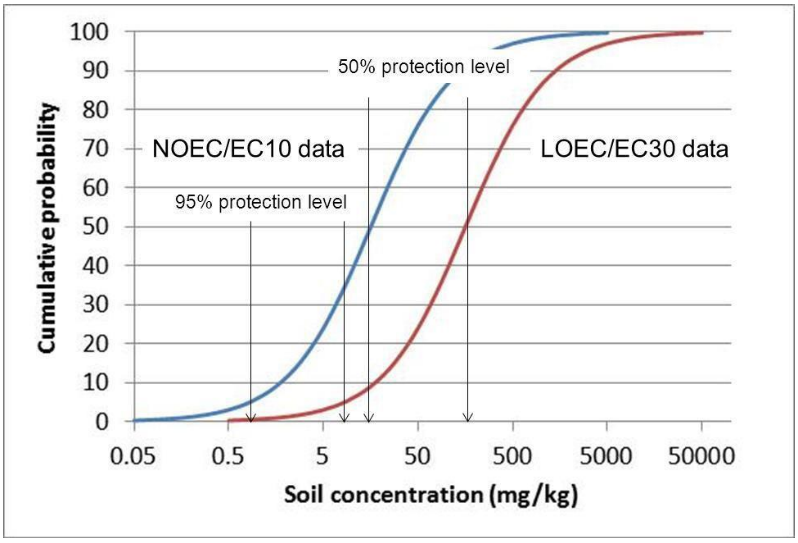

Figure 2 Graph of a hypothetical species-sensitivity distribution, illustrating the potential influence of the selection of different toxicity endpoints and protection levels on derived Eco-SGVs –ranging from ~0.6 to ~350 mg/kg in this example.

This report provides the basis for discussion at workshops on the methodology and application of Eco-SGVs to be held with various stakeholder groups including regional councils, organic waste sector, and contaminated land practitioners. Within the proposed methodology, different decisions can be made about the choice of toxicological data used and the level of protection afforded by the Eco-SGVs that ultimately determines the final “number” that is developed (Figure 1). These decisions are more a matter of policy and consensus rather than science, and should take into account the intended application of the Eco-SGVs. An update on the determination of background concentrations using existing data is also provided, along with discussion of aspect to consider for developing a database to enable ongoing capture and use of trace element data.

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