Manaaki Whenua
Landcare Research

UPDATED Development of soil guideline values for the protection of ecological receptors (Eco-SGVs): Technical document

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Updated Development of soil guideline values for the protection of ecological receptors (Eco-SGVs): Technical document

Contract Report: LC2605 (updated)

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Summary

The report has presented a methodology for deriving soil guideline values (Eco-SGVs) that are protective of microbial processes, plants, soil invertebrates, wildlife and livestock in New Zealand. This methodology was developed in consultation with stakeholders to facilitate the development of Eco-SGVs that are suitable for use. A user guide (Cavanagh 2016) accompanies this technical document, and a further report provides the technical background to the determination of background soil concentrations across New Zealand (Cavanagh et al. 2015). This methodology was used to develop Eco-SGVs for eleven contaminants (arsenic, boron, cadmium, chromium, fluorine, and lead (Table 53); copper, and zinc (Table 54); TPH, DDT and PAHs (Table 55)). These substances were selected as they have a variety of physicochemical properties and, as a result, behave differently in the environment. Contaminants selected include the most common contaminants as well as contaminants for which toxicity to livestock (fluoride) or bioaccumulation in wildlife (DDT) need also to be considered.

The Eco-SGVs developed for use are predominantly based on the LOEC/EC30 toxicity endpoint for aged contamination. For all inorganic contaminants sufficient data were available to use the SSD approach to derive ACLs. These were added to the range in median background concentrations for the different elements determined by Cavanagh et a.l (2016), except for boron for which Eco-SGVs are expressed as hot-water soluble boron concentrations and for which background concentrations are expected to be negligible. Relationships to normalise toxicity data to soil properties were available for microbes, plants, and soft-bodied and hard-bodied invertebrates for Cu and Zn, thus Eco-SGVs were able to be developed for the three New Zealand reference soils (Table 53). As Cu and Zn present in urban stormwater, which may be discharged to land, is in a form similar to that in freshly spiked soils, Eco-SGVs for fresh and aged contamination were developed for Cu and Zn. For Cr, normalisation relationships were only available for soft-bodied invertebrates although this made no practical difference to ACLs derived for the three New Zealand reference soils so only one generic set of Eco-SGVs was developed. Generic ACLs were developed for As, B, Cd, and Pb and are considered applicable to all soil types for the appropriate land use. As Cd biomagnifies in the food chain, Eco-SGVs are based on a higher protection level compared to non-biomagnifying contaminants. While Pb is not considered to biomagnify per se, there may be potential for secondary poisoning to occur at higher Pb concentrations; thus for the residential/recreational and commercial/industrial land uses, Eco-SGVs based on a higher level of protection are also provided.

There were limited toxicity data available for the organic contaminants. Utilisation of older studies (i.e. pre-1970) yielded additional data for DDT, and sufficient to use the SSD approach for deriving ACLs. The main residue typically present in soils as a result of the historical use of DDT is DDE, the main degradation product of DDT. However, a dearth of data on the toxicity of DDE to soil microbes, plants and invertebrates precludes the development of an Eco-SGV for DDE. To address this, and given the observation of marked biomagnification of DDE in a New Zealand food chain, more conservative DDT Eco-SGVs were recommended for use. In this case, the Eco-SGVs were based on the NOEC/EC10 toxicity endpoints, and accounted for biomagnification (i.e. a higher protection level was used to set the Eco-SGV).

Eco-SGVs are developed for TPH and PAHs (fluoranthene, benzo(a)pyrene). These values are recommended for use as screening criteria only as these compounds are typically present as mixtures of varying composition, and therefore toxicity, and they are based on limited toxicity data

Abbreviations/Glossary

ACL	Added contaminant limit
ALF	Ageing leaching factor
DDE	Dichlorodiphenyldichloroethylene
DDT	Dichlorodiphenyltrichloroethane
Eco-SGV	Ecological soil guideline value
ECx	Effect concentration – concentration at which x% effect has been observed
Eco-SSL	Ecological soil screening level
LOAEL	Lowest observed adverse effect level, equivalent to LOEC
LOEC	Lowest observed effect concentration
LRIS	Land Resource Information Systems – an online repository of information on environment and land resources of New Zealand (https://lris.scinfo.org.nz/)
NEC	No effect concentration
NOAEL	No observed adverse effect level, equivalent to NOEC
NOEC	No observed effect concentration
NOEC	No observed effect concentration toxicity endpoint
PAH	Polycyclic aromatic hydrocarbons
PNEC	Predicted no effect concentration – contaminant concentration below which no effects on ecological receptors are expected to be observed.
PNR	Potential nitrification rate
RBC	Risk-based concentration
SIN	Substrate induced nitrification
SINDI	Online soil quality indicators database available at https://sindi.landcareresearch.co.nz/
SIR	Substrace induced respiration
SQG	Soil quality guideline – a generic term used to describe a numeric value developed using different methologies to provide a measure of soil quality.
SSD	Species sensitivity distribution, – generated by fitting a statistical distribution function to the proportion of species affected by increasing contaminant concentrations
TPH	Total petroleum hydrocarbons

1 Introduction

Soil guideline values developed to protect terrestrial biota (soil microbes, invertebrates, plants, wildlife and livestock) (Eco-SGVs) provide a useful means to readily assess potential environmental impact. Some soil guideline values already exist in New Zealand, for example 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.

Specifically, under the Resource Management Act (Section 30), regional councils and unitary authorities have responsibilities to safeguard the life-supporting capacity of soil and ecosystems, and ensure any adverse effects on the environment are avoided or mitigated and do so by managing soil quality and land. This includes regulating the discharge of contaminants and managing contaminated land. A fundamental aspect of ensuring regional councils are able to fulfil these responsibilities is to have a clear understanding of the potential effect of hazardous substances on terrestrial biota. Similarly, under Section 31, territorial authorities have responsibilities that include the control of any actual or potential effects of the use, development, or protection of land, including contaminated land, essentially ensuring that land is 'fit for purpose'. Clarity is required around the extent to which regional councils, territorial authorities and central government consider that these obligations are being effectively met in relation to the terrestrial environment to define the scale of the problem.

However, the lack of an effective tool for terrestrial ecological risk assessment is considered to have resulted in patchy and inconsistent approaches to environmental protection currently. As a result, developing national guidelines to protect the environment is a top priority for the Regional Waste and Contaminated Land Forum (RWCLF, refer Document #1779443 *Research priorities: Regional Waste and Contaminated Land Forum* October 2010 held by the Waikato Regional Council). Furthermore, determining the extent of soil contamination and how to manage it are identified as a critical issue for both the Land Monitoring Forum (LMF) and the Land Management Group (LMG; refer *Alignment of Land Special Interest Groups and the National Land Resource Centre Priorities*, Weeks & Collins 2013). Finally, development of nationally consistent methods for determining soil contaminant levels and numbers is identified as 'high priority' in the Ministry for the Environment's 2007 Discussion Paper *Working towards a comprehensive policy framework for managing contaminated land in New Zealand*. That document formally recognises the absence of guidance for addressing ecological impacts of contaminants in soil.

To address these gaps, the Envirolink tools project 'Background concentrations and soil guideline values for the protection of ecological receptors' (Eco-SGV tools project) commenced in July 2014 with the objectives 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 for ensuring environmental protection (e.g. cleanfill criteria).

This report provides the detailed technical background to the development of Eco-SGVs, and an overview of the intended application. A further report (Cavanagh 2016) provides the details on the intended application of background concentrations and Eco-SGVs and is the primary document that should be referred to for the use of background concentrations and Eco-SGVs. A final report provides the detailed technical background to the development of background concentrations for a suite of trace elements and organic contaminants, and database requirements (Cavanagh et al. 2016). Information of background soil concentrations from specific locations is also available at LRIS (https://lris.scinfo.org.nz/).

1.1 Update 2019

In 2019, this technical document and the User Guide (Cavanagh 2016) were updated following review (Kim 2018) and the release of international guidance (OECD 2017) and tools (Oorts 2018) to assist in the development of threshold values for soil. Briefly, these updates included revision of the EcoSGVs for copper, zinc and arsenic, and expression of boron EcoSGVs as hot-water soluble boron concentrations. Some changes in the text to improve clarity in some areas or around intended application including

- Explicitly stating that the fluorine EcoSGVs were not sufficiently robust for use
- That the BM values for Cd and Pb (for residential and commercial landuse) are preferred for use.

Full details are available in Cavanagh 2019.

2 Process

An advisory group comprised of 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 has overseen the project. The advisory group confirmed the range of receptors to be considered in the development of Eco-SGVs (Figure 1), and the contaminants for which Eco-SGV were derived (Table 1). Contaminants selected have different physico-chemical properties and thus behave differently in the environment. Thus, contaminants selected included the most common contaminants as well as contaminants for which toxicity to livestock (fluoride) or bioaccumulation in wildlife (DDT) need also to be considered.

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

Table 1 Priority contaminants for the development of Eco-SGVs

Inorganic contaminants	Organic compounds
Arsenic (As)	Dichlorodiphenyltrichloroethane (DDT)
Boron (B)	Total petroleum hydrocarbon (TPH)
Copper (Cu)	Polycyclic aromatic hydrocarbons (PAH)
Cadmium (Cd)	
Chromium (Cr)	
Fluoride (F)	
Lead (Pb)	
Zinc (Zn)	

Actual values for Eco-SGVs are determined by decisions can be made about the toxicological data used and the level of protection afforded by the Eco-SGVs. 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. A series of workshops were held to provide input to the development of the methodology. These workshops were held with

- regional councils (contaminated land, soil quality and policy, March 2015),
- organic waste sector (March 2015)
- contaminated land practitioners (April 2015).

Prior to the workshops, a discussion document was circulated. This report provided the details of the proposed approach and developed a range of Eco-SGVs for copper and zinc to to illustrate how decisions on the toxicological data and level of protection afforded affected the actual value.

To obtain further insight into implementation of the Eco-SGVs, presentations were also made to regional council Policy Managers Special Interest Group (SIG), Compliance & Enforcement SIG and the Consent Managers SIG. Presentations have also been given to the Australasian Land and Groundwater Association (Auckland July 2015, Christchurch November 2015), the WasteMINZ conference (October 2015) and the Fertiliser & Lime Research Centre (FLRC) Workshop to enable stakeholder feedback. Finally, presentations have been given at a scientific conference (Society of Environmental Toxicology and Chemistry, August 2015) to provide technical peer review of the proposed approach. Regular updates have also been provided to the Cadmium Management Group, comprised of representatives of central and local government and agricultural industry sector groups who are overseeing the national management of soil cadmium.

The outcomes of these workshops and presentations are outlined below.

Choice of effect level: Eco-SGVs may be derived using different effect levels. Most often the NOEC (no observed effect concentration) or EC10 (effective concentration at which effects are observed in 10% of the test population) is used. Other endpoints may be used such as the LOEC (lowest observed effect concentration), EC30 (effective concentration at which effects are observed in 30% of the test population), EC50 (effective concentration at which effects are observed in the 50% of the population) or LC50 (the concentration at

which mortality is observed in 50% of the population). The potential influence of different toxicological endpoints and level of protection on the final derived Eco-SGV value is shown in Figure 2.

For the current work, Eco-SGVs were agreed to be derived on the basis of EC30 values, taking account of ageing and leaching effects. Exceptions to this were that Eco-SGVs were also derived for fresh contamination for copper and zinc, which are key contaminants in stormwater discharge that may be applied to land.

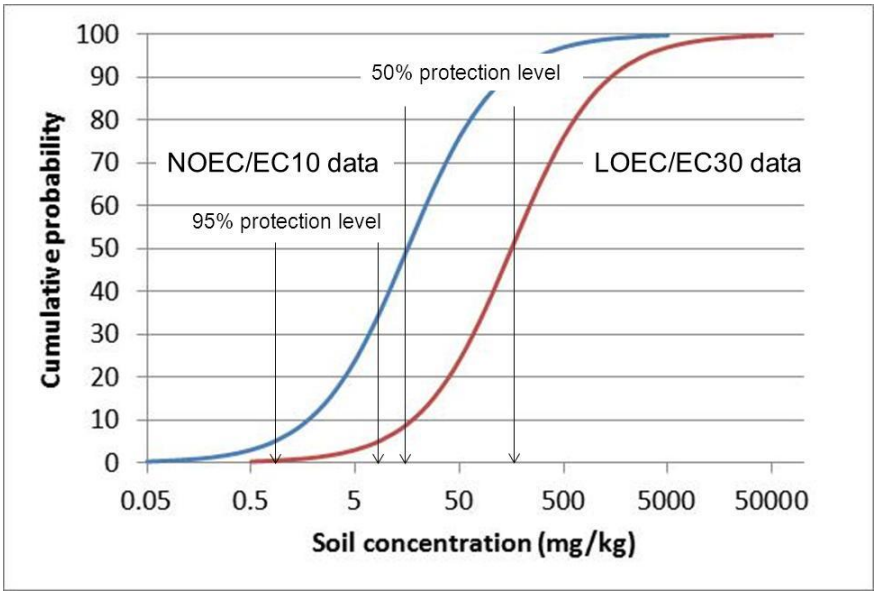

Figure 2 Hypothetical species-sensitivity distribution, illustrating the potential influence of the selection of different toxicity endpoints and protection levels on derived Eco-SGVs, ranging from c. 0.6 to c. 350 mg/kg in this example.

Level of protection: Different land uses have specific functions and species that should be protected in order to ensure the land can continue to be used for that purpose. Providing different levels of protection based on different land uses provides a cost-effective and pragmatic approach to contaminant management. The functions and species for protection include plants, soil microbial processes, soil and terrestrial invertebrates and vertebrates. Further, there are multiple potential exposure pathways for terrestrial ecosystems, although not all exposure pathways will be relevant for all land uses. For example, exposure pathways that involve biomagnification are unlikely to be relevant to small industrial sites, as their surface area is limited. The extent to which the species and ecological functions will be protected – using the preferred method for deriving Eco-SGVs (that is, species sensitivity distribution (SSD) methods), it is possible to protect a hypothetical percentage of species/ecological functions (e.g. 99% or 95%). The level of protection can be changed depending on land use. For example, relatively low protection could be provided for commercial/industrial areas, and high protection for national parks and other lands with high ecological value.

A summary of the land use categories, receptors covered and the associated level of protection that arose from workshop discussions are shown in Table 2.

Table 2 Summary of land use categories, land use covered under the National Environmental Standard for Assessing and Managing Contaminants in Soil (NES), receptors covered and level of protection of plants, soil processes and invertebrates for Eco-SGVs

Land use	NES land use	Additional land uses covered/Description	Receptors covered	Level of protection (%)[1]	
				Plants	Soil processes/ invertebrates
Commercial /Industrial	High density residential, Commercial / industrial outdoor worker	Road reserves. All commercial/industrial and high-density residential land use, including under paved areas. Highly artificial ecosystems but soils should still support the basic soil processes and be able to recover if land use changes.	Soil microbes, plants, invertebrates Soil and food ingestion, Trigger for off-site impacts	60 (65)	60 (65)
Residential and recreational areas	Rural residential/lifestyle block (25% produce consumption) Residential (10% produce consumption) Recreational areas	Modified ecosystems but for which there is still an expectation that important species and functions can be maintained.	Soil microbes, plants, invertebrates, wildlife	80 (85)	80 (85)
Agriculture, including pasture, horticulture and cropping	Production land[2]	All food production land. The protection of crop species is required to maintain the sustainability of agricultural land. Soil processes and soil invertebrates are highly important to ensure nutrient cycling to sustain crop species but tillage and use of pesticides mean it is not realistic to have the same level of protection as for plant species.	Soil microbes, plants, invertebrates, wildlife and livestock	95 (99)	80[3] (85)
Non-food production land	Production land	All non-food production land (e.g. production forestry) to which waste could be applied and which does not fall into other land use categories. Similar to agricultural land, although tillage and pesticide application is not expected to affect soil processes and soil invertebrates, enabling a higher level of protection for these organisms.	Soil microbes, plants, invertebrates, wildlife	95 (99)	95 (99)
Ecologically sensitive areas	NA	National Parks, designated ecologically sensitive areas. Near-pristine ecosystems that should remain in that condition.	Soil microbes, plants, invertebrates, wildlife	99	99

[1] This is based on using EC30/LOEC toxicity data and aged contamination for all applications except discharge of stormwater, for which contamination should be considered fresh (due to the high organic load in organic wastes such as chicken manure, it is considered that aged contamination is appropriate). The value in brackets is the level of protection that should be provided for biomagnifying contaminants. Due to mathematical constraints, if the level of protection is 95%, the increased level of protection is 99%.

[2] NES regulations state: If the land that is potentially or actually affected by contaminants is production land, the regulations do not apply to:

a. soil sampling or soil disturbance (except on parts of production land used for residential purposes)

b. subdivision or change of use (except where that would result in production land being used for a different purpose, eg, for residential land use).

[3] lower protection level in recognition of intentional pesticide application, and cultivation effects; NA –Not applicable.

Application of Eco-SGVs and background concentrations of trace elements: In general, Eco-SGVs and background soil concentrations are intended to be used for two key purposes:

- Management of contaminated land
- Protection of soil quality.

With respect to contaminated land management, Eco-SGVs are intended to (i) inform remediation (primarily through setting standards for the quality of any soil imported onto site), where remediation is already occurring or (ii) instigate further investigation where there is significant exceedance of Eco-SGVs. It is not intended that exceedance of the Eco-SGV will drive remediation unless further investigation determines on-site or off-site effects are occurring (see User guide). (iii) identify contaminated land with respect to land to HAIL category I to determine whether a hazardous substance present at concentrations above background concentrations could be a risk to the environment.

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 biowastes such as municipal 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 biowastes do not result in detrimental effects on soil biota (i.e. to ensure any adverse effects on the environment are avoided or mitigated). Eco-SGVs are intended to inform consent limits for application of wastes (e.g. managed fill, clean-fill, organic wastes) and in this respect are 'pollute-up-to' criteria. *In setting criteria for waste disposal, protection of human health and groundwater resources should also be considered, thus Eco-SGVs are only one component for consideration.*

Finally, Eco-SGVs are also intended to provide a benchmark for assessing soil quality over time in relation to regional council State of the Environment monitoring – ultimately this could also be linked to ecosystem services (i.e. exceedance indicates a certain ecosystem service may be impacted).

A summary of the proposed application of Eco-SGVs is provided in Table 3.

Table 3 Proposed application of Eco-SGVs for each land-use category and purpose

Land-use category	Contaminated land management	Protection of Soil quality
Commercial /Industrial	Inform remediation standards[1] – specifically the quality of any soil imported onto site Trigger further site investigation, including off-site effects, in the event of significant exceedance[2]	na
Residential and recreational areas	As above Identification of contaminated land	Informing consent limits for application of wastes (e.g. biosolids, cleanfill, managed fill) to land Regional council State of the Environment monitoring
Agriculture	As above[3]	As above
Non-food production land	As above[3]	As above
Ecologically sensitive areas	As above[3]	As above

[1] noting that Eco-SGVs for copper and zinc, in particular, should not automatically be applied as remediation standards – the effect of excavation and disposal of soil should be considered relative to the effect of actively managing the land to reduce concentrations over time.

[2] >2 times the Eco-SGV over an area of 25 m^2

[3] Most likely in relation to small areas of contamination such as sheep dips, pesticide sheds.

na – not applicable

2.1 Related projects

There are two related projects that have been undertaken ('Land disposal guidelines') or are nearing completion ('Beneficial use of organic waste') 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 this Envirolink 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 project is used to inform the criteria or limit-setting where these relate to background soil concentrations or protection of ecological receptors.

A key difference between 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.

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

2.1.1 Land disposal guidelines

Technical Guidelines for Disposal to Land have been completed and are available on the WasteMINZ website (http://www.wasteminz.org.nz/pubs/technical-guidelines-for-disposal-to-land-april-2016/). The document provides technical guidance on siting, design, construction, operation, and monitoring for disposal to land, and classifies landfills 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 Envirolink 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 for trace elements (Appendix C in WasteMINZ 2016). Appendix C provides an overview of the development of waste acceptance criteria, which includes consideration of leaching potential, human health exposure, and exposure of ecological receptors, and Appendix G (in WasteMINZ 2016) provides Class 4 waste acceptance criteria, using regional background concentrations for key inorganic elements in Auckland and Wellington as examples, and specified criteria for selected organic contaminants. Background soil concentrations developed in the current study will assist in providing background soil concentrations for specific locations and other regions.

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. Appendix C (in WasteMINZ 2016) 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 (in WasteMINZ 2016) and are a mix of criteria for the protection of human health, ecological receptors, and aquatic receptors.

2.1.2 Guideline 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 (WaterNZ, WasteMINZ, Centre for Integrated Biowaste Research (CIBR), and the Land

Treatment Collective (LTC)) together with representation from the Ministry for the Environment, Ministry for Primary Industries, Ministry of Health, and an environmental NGO. 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. A draft guideline has been developed for the project's steering group, and a second draft is currently being prepared based on feedback from that group. (N Walmsley, WaterNZ, pers. comm.). Consultation on the draft is expected during the 3rd quarter of 2016.

3 The methodology

3.1 Background

Comprehensive review of international approaches to developing soil guideline values for the protection of ecological receptors, generically soil quality guidelines (SQG), has been provided in Cavanagh and O'Halloran (2006) and MPI (2012). The latter also provided recommendations for a proposed approach for developing Eco-SGVs for cadmium that are developed further in Cavanagh (2014). 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).

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 methods 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 by 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 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-SGVs, and the use of the 'added-risk ' approach for developing Eco-SGVs for metals (Checkai et al. 2014, Greenberg 2014). The incorporation of soil characteristics in the toxicity assessment includes normalisation to a standard soil and accounting for ageing and leaching. 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. 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). However, it is noted that within the EU the added-risk approach has been variably used in risk assessments conducted under the REACH programme. Notably the added risk approach is used in the Zinc Risk Assessment Report (RAR) (EC 2008), but not in the Copper RAR (ECI 2008), although added risk values are provided in annex 2 of ECI (2008). The reservations in use appear to primarily stem from the view of the Scientific Committee on Health and Environmental Risks, which reviews many of the risk assessment reports, that the absence of region-wide background soil concentrations limits the ability to use the added-risk approach (e.g. SCHER 2009). This project has established background soil concentrations for a considerable area across New Zealand (Cavanagh et al. 2016) and so avoids this limitation.

3.2 Methodology

3.2.1 Overview

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
- normalisation of the toxicity data to New Zealand reference soils (only if the SSD approach is used to calculate the ACL)
- calculation of an added contaminant limit (ACL) by either the species sensitivity distribution (SSD) or assessment factor (AF) approach, depending on the toxicity data
- 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.

3.2.2 Data compilation and screening

There has been a considerable amount of data for selected contaminants collated and evaluated in the development of both the Australian EILs (NEPC 2013a) and under the REACH programme (EC 2007, 2008; ECI 2008; LDAI 2008). Through both these processes, the quality of the data has been screened for relevance and quality. The first step in compiling data was to obtain the data used by different agencies to identify data suitable for use, and any difference in the selection of data used. Sources include http://echa.europa.eu/web/guest/information-on-chemicals/registered-substances), substance-specific risk assessment reports (e.g. EC 2008a,b) and data provided in NEPC (2013b). Additional data were provided by Cavanagh and O'Halloran (2006) and Cavanagh (2006) and by literature review to identify any more recent studies (in particular from 2009

on) that might be of use. Detailed data screening is described in NEPC (2013a), although a simplified approach was used in the current work. The key factors evaluated were:

- Toxicity tests in soil media only have been used in this report. Tests performed in substrates that were judged as not representative for soils (e.g. nutrient solution, agar, pure quartz sand and farmyard manure) were not included.
- Toxicological endpoints considered have direct effects at population level (e.g. mortality, growth and reproduction for plants and invertebrates). Soil microbial endpoints are functional variables, such as C- and N-mineralisation, and enzymatic processes.
- Data from chronic toxicity tests are preferred over acute (mortality) studies.
- Effect levels are reported, and a dose-response was observed.

Despite the search for newer literature, the bulk of the studies used for the development of Eco-SGVs are older toxicological studies (i.e. pre-1990). Substantial newer data have been generated for cadmium, lead, copper and zinc, arising out of research to meet REACH regulations (EC2007, 2010; ECI 2008, LDA2008a). Studies older than 1970 were generally excluded unless data were scarce (DDT).

3.2.3 Selection of toxicity data

The toxicity data predominantly used are those that have sub-lethal endpoints, and typically can be considered chronic (long-term) studies.

- For plants this includes biomass (above and below ground), seedling emergence, root and shoot elongation, yield, and seed production.
- For invertebrates, measured endpoints are typically growth and reproduction (number of juveniles or cocoons).
- Microbial tests use chemical endpoints related to soil functions or processes that are closely linked to biogeochemical processes linked to soil fertility. Some examples include potential nitrification rate, soil respiration, nitrogen mineralisation and enzymes such as phosphatase. Preference is given to non-enzymatic data, but these are the only data available to assess the effect of contaminants on the phosphorous and sulphur cycles.

Eco-SGVs may be derived using different effect endpoints. Most often the NOEC (no observed effect concentration) or EC10 (concentration at which a 10% reduction in the relevant endpoint is observed) is used. Other endpoints may be used such as the LOEC (lowest observed effect concentration), EC30 (concentration at which a 10% reduction in the specified endpoint is observed), EC50 (concentration at which a 10% reduction in the relevant endpoint is observed or LC50 (the concentration at which mortality is observed in 50% of the population). The endpoint chosen partly depends on what is reported in the literature; specifically, older literature typically reports NOEC or LOEC type data, whereas more recent literature tends to report the effect on a certain percentage of the test population (EC*x*). More recently, a shift has been seen to statistical model-based toxicity measures of no effect concentrations (NEC), which is suggested to be the preferred toxicity endpoint for the development of aquatic guideline values (Batley et al. 2014). EC10 can be considered equivalent to NOEC, while EC30 can be considered equivalent to LOEC

(Heemsbergen et al. 2009). Following NEPC (2013a), for the purposes of this methodology, toxicity data relating to less than a 20% effect (e.g. EC_0 to EC_{19}) are considered equivalent to NOEC data. Toxicity data relating to a 20–40% effect are considered equivalent to LOEC data and are referred to throughout this guideline as LOEC/EC_{30} data. Toxicity data relating to >40–60% effect are considered equivalent to EC_{50} data and are referred to as EC_{50} data.

Toxicity with an effect greater than 60% should not be used. If the highest tested concentration did not cause an effect or a statistically significant effect on the test species (that is, an unbounded NOEC), then the toxicity data should be given a 'greater than' value and can be treated as an EC_{10}. This provides a conservative approach resulting in more toxicity data available for soil quality guideline (SQG) derivation. Judgement should be used to determine if it is appropriate to include these unbounded values in the SSD (Batley 2014).

To maximise the data available to derive Eco-SGVs, toxicity data can also be converted to different endpoints using conversion factors. For As, F, DDT, PAH and B the default conversion factors were those used in the Australian and New Zealand water quality guidelines (Table 4). For cations (Cd, Cr (III), Cu, Pb, Zn) the conversion factors determined from the Australian National Biosolids Research programme for copper and zinc were used where required (Table 5).

Table 4 Default conversion factors used to convert different chronic measures of toxicity to chronic NOECs in the Australian and New Zealand Water Quality Guidelines (ANZECC & ARMCANZ 2000). Values are from NEPC (2013a)

Toxicity data[a]	Conversion factor
EC_{50} to NOEC or EC_{10}	x 5
LOEC or EC_{30} to NOEC or EC_{10}	x 2.5
MATC* to NOEC or EC_{10}	x 2

[a]EC_{50}, EC_{30} and EC_{10} values are the concentrations that cause a 50%, 30% or 10% effect, NOEC = the no observed effect concentration, LOEC = lowest observed effect concentration.

*MATC = the maximum acceptable toxicant concentration and is the geometric mean of the NOEC and LOEC.

Table 5 Conversion factors used to convert various measures of toxicity for cations such as copper and zinc. The conversion factors were obtained from unpublished data from the Australian National Biosolids Research Program and were cited by NEPC (2013a)

Data being converted[a]	Conversion factor
NOEC or EC_{10} to EC_{50}	x 3
NOEC or EC_{10} to LOEC or EC_{30}	x 1.5
LOEC or EC_{30} to EC_{50}	x 2

[a]EC_{50}, EC_{30} and EC_{10} values are the concentrations that cause a 50%, 30% or 10% effect, NOEC = the no observed effect concentration, LOEC = lowest observed effect concentration.

EC30 was considered to be the preferred toxicological endpoint for deriving Eco-SGVs in New Zealand, and is consistent with the approach used to derive EILs in Australia (NEPC 2013a). Preference was given to EC30 determined from dose-response curves (most often EC20 or EC25s) or from percentage effect data, followed by EC30 derived from EC10 or EC50 and finally LOEC and NOEC data (Table 6). The categories shown in Table 6 are used to indicate the basis of the LOEC/EC30 values in Appendices B – L. Most of the toxicity measures were based on EC10 or NOEC data. Frequently, an EC50 was derived using a dose-response relationship along with a statistically determined NOEC (and sometime LOEC); in this case professional judgement was used to determine whether an EC30 based on conversion of EC50, or LOEC or NOEC provided a better representation of the EC30. EC30 derived from NOEC and LOEC were the least preferred, in recognition of the debate about the suitability of the NOEC as a measure in toxicity testing (e.g. Chapman et al. 1996; Warne & van Dam 2008; Fox et al. 2008). Where a statistically derived EC10 was less than half the lowest dose tested, it was excluded from the data compilation as it was deemed too uncertain. In this case, the reported NOEC or LOEC was used if the effect level of the lowest concentration was reported, and it lay within the percentages expressed above. Where studies provided data at different exposure times, toxicity endpoints associated with the longest exposure time were preferentially selected.

Table 6 Order of preference for determination of LOEC/EC30 values, and associated category.

Category	Description
1	EC20/30 has been provided by statistical analysis, or % effect level (20–40%) provided in original study
2	EC30 derived from EC10 provided by statistical analysis or % effect level (<19%) provided in the original study
3	EC30 derived from EC50 provided by statistical analysis or % effect level (40–60%) provided in the original study
4	LOEC provided in original study
5	NOEC provided in original study

While there can be debate as to whether toxicity data for overseas species should be used, as it assumes that they have the same sensitivity as endemic species (e.g. Dyer et al. 1997; Markich & Camilleri 1997; Kwok et al. 2007), from a statistical perspective SQGs become increasingly reliable as the number of species for which there is toxicity data increases. Further, there is limited toxicity data for New Zealand endemic terrestrial species, and none found that were suitable for derivation of Eco-SGVs. Thus all available data were used, provided they met the quality criteria. All available toxicity data have similarly been considered for use in the development of predicted no effect concentrations (PNECs) in the European Union (e.g. EC 2007, 2008; ECI 2008) or ecological investigation levels (EILs) in Australian NEPCs (2013a).

Toxicity data expressed as either added or total soil concentrations were included, given evidence (Smolders et al. 2003, 2004; Oorts et al. 2006; Zhao et al. 2006, Broos et al. 2007; Warne et al. 2008b) that chemical extract concentrations (e.g. calcium chloride, ammonium nitrate and soil solution extracts) of inorganic contaminants are not necessarily better

measures of bioavailability than total concentrations. Furthermore, there are also considerably more toxicity data expressed as total metal concentration, and there is regulatory acceptance and understanding of this concentration measure (NEPC 2013a).

In most cases, the *added* concentration is easy to determine as studies report the amount of a substance *added* to the test media. However, in some cases the toxicity measures are reported on the basis of measured concentrations; this provides the *total* concentration (i.e. the background soil concentration + the amount added). In this case, the background concentration can be subtracted from the total concentrations to provide the added concentration. If background concentrations are not given, a default background level can be set or the background concentration can be assumed to be zero.

3.2.4 Incorporation of an ageing and leaching factor

Typically, soil toxicity tests use soils that have been freshly spiked (e.g. with metal salt solutions) with the contaminant in question. This does not allow effects of ageing or leaching on toxicity to be taken into account. Ageing or natural immobilisation (attenuation) is the process by which many contaminants (both inorganic and organic), when added to soil, will bind over time to various soil components (Hamon et al. 2007; Smolders & Degryse 2007) and this can reduce the concentration of the contaminant that is biologically available (McLaughlin et al. 2000a). Leaching is a process that removes readily soluble soil components such as salinity from soils. Some studies have attributed the effects observed in some toxicity studies to acidification and salinity arising from the addition of metal salts typically used in toxicity studies (e.g. Spier et al 1999; Smolders et al. 2015)

A study by Smolders et al. (2009) derived ageing/leaching factors (ALFs) for Zn, Cu, Ni, Co, Pb, Cd based on toxicity measures in a variety of European field and freshly spiked soils. These ALFs have been used in the derivation of the Australian EILs, as well as in EU risk assessment (EC 2008; ECI 2008; LDAI 2008). Additionally, NEPC (2013a) developed ageing/leaching factors (ALFs) for As and Cr. Smolders et al. (2015) also undertook further investigation to identify the relative contribution of different factors (i.e. salinity, acidification and ageing) to Pb toxicity. This study was used to assess the ALF for Pb. A summary of the ALFs used to derive Eco-SGVs and their source is shown in Table 7, with further discussion on the basis for the ALF provided in the section for each individual contaminant.

Table 7 Summary of ageing-leaching factors (ALFs) used for the development of Eco-SGVs

Trace element	ALFs	Source
As	2	NEPC 2013a
Cd	1	Smolders et al. 2009
Cr	2.5	NEPC 2013a
Cu	2	Smolders et al. 2009, ECI 2008
Pb	4.2	NEPC2013a, LDAI 2008
Zn	3	Smolders et al. 2009, EC 2008

3.2.5 Normalisation of toxicity data to New Zealand reference soils

It is well recognised that soil properties (e.g. pH, cation exchange capacity (CEC), organic matter, clay content) can influence the observed toxicity associated with contaminants (e.g Smolders et al 2004, Song et al 2006, Warne et al 2008a). Normalisation relationships attempt to minimise the effect of soil characteristics on the toxicity data so the resulting toxicity data will more closely reflect the inherent sensitivity of the test species to the contaminant. Normalisation should only be undertaken where there are sufficient data to use the SSD method.

While a large number of studies have investigated the influence of soil properties on toxicity, fewer utilise commonly measured soil properties (total carbon/organic matter, pH, cation-exchange capacity). There are limited data available for normalising toxicity data (Li et al. 2003; Smolders et al. 2004; McLaughlin et al. 2006; Song et al. 2006; Broos et al. 2007; Warne et al. 2008a, b). To maximise the use of available data, four groups are considered to represent an ecosystem: plants, soft-bodied invertebrates (worms, nematodes), hard-bodied invertebrates (springtails, mites) and microbial (including fungi) functional endpoints. Thus, if a normalisation relationship exists for a species in one of these groups, the relationship can be applied to all species in that group.

Following NEPC (2013a), the choice of relationships to normalise the toxicity data was based on (1) regional relevance (i.e. relationships derived from European data were used to normalise European data, relationships derived from Australian data were used to normalise Australian data), (2) whether they are based on field- or laboratory-based toxicity data, with preference given to field-based relationships, (3) whether they provide a conservative SQG – normalisation relationships with lower gradients will provide lower normalised toxicity values and thus lower SQGs (EC 2008a), (4) the quality of the relationship as indicated by the coefficient of determination (r^2) , and (5) the number of species to which the relationships apply.

During the collation of toxicity data, soil property information provided for a study was recorded. If needed, where CEC was not provided, it was estimated from % clay, % organic carbon (OC) and pH using the following equation (Helling et al. 1964):

CEC = (30.4 + 4.4*pH)*%clay/100 + (-59+51*pH)*%OC/100

Or using organic matter (OM)

CEC = (30.4 + 4.4*pH)*%clay/100 + (-35+30*pH)*%OM/100

This yields CEC at soil pH or the effective CEC. If the soil properties required for normalisation are unknown, the associated toxicity data cannot be used for normalisation.

Toxicity data are normalised using the corresponding slopes to 'reference' soil properties (the abiotic factors: CEC, organic carbon, clay or pH), following Smolders et al. (2009):

$$ECx_{ref} = ECx_{test} \left[\frac{abiotic_{ref}}{abiotic_{test}}\right]^{slope}$$

Where ECx_{ref} is the level of effect (x) in the reference soil (ref) or test soil (test); $abiotic_{ref/test}$ is abiotic factor influencing toxicity in the reference soil (ref) or test soil (test), slope is the coefficient of the regression equation for the relevant abiotic factor.

If a statistically significant relationship ($p \leq 0.05$, $R2 > 0.6$; Warne et al. 2008b, NEPC 2013a) between toxicity data and soil characteristics can be demonstrated, the toxicity data should be normalised to the New Zealand reference soils. Three reference soils were described to provide a 'sensitive' soil, a 'typical' soil and a 'tolerant' soil. The properties of these soils were based on professional judgement and data held within the National Soils Database (NSD). Recent soils were chosen to represent a sensitive soil as these soils typically have low organic content and CEC and thus may be expected to have a greater availability of contaminants. Brown soils were selected to represent typical soils as these are the most common soils across New Zealand. Allophanic soils were chosen to represent tolerant soils as they have a high sorption capacity for contaminants, and thus would be expected to exhibit lower toxicity. Data on CEC, clay content, organic C and pH were extracted from the NSD, and the median value used to provide properties of the three reference soils (Table 8). Soil pH was similar across the three soils but may be an important variable influencing toxicity.

Cation exchange capacity, pH and organic carbon are commonly measured factors that are considered to have the greatest influence on the toxicity of contaminants. In these studies pH is typically expressed as pH measured in $CaCl_2$, which is different to that typically used in New Zealand (pH measured in water). However, these can be related according to

$$pH_{CaCl2} = 0.9761 * pH_{H20} - 0.427 \ (R^2 = 0.92, n=1997) \text{ (JRC undated)}$$

Cation exchange capacity used in normalisation relationships is typically expressed as the CEC at native soil pH or the effective CEC. This differs from CEC measured at pH 7, which is typically the method used in New Zealand. Thus CEC measures for reference soils were adjusted to effective CEC using the equation above, although they were found to be very similar (Tables 8 & 9).

Table 8 Soil characteristics for New Zealand reference soils to be used to normalise toxicity data. Properties were determined from the National Soils Database; values in parenthesis are the number of samples used to determine characteristics; CEC = cation exchange capacity

Soil property	Sensitive soil (Recent soil)	Typical soil (Brown soil)	Tolerant soil (Allophanic soil)
pH (H_2O)	5.0[1]	5.4 (170)	5.5 (55)
Clay (%)	17 (83)	21 (216)	23 (49)
CEC (cmol/kg)	13 (154)	20 (366)	30 (103)
Org. carbon (%)	3.1 (159)	4.6 (363)	9.4 (101)

Notes: values in parenthesis are the number of samples used to determine characteristics; CEC = cation exchange capacity. [1]The actual mean pH for recent soils was 5.7 (greater than both the typical soil, and tolerant soil), but as soils with lower pH often have greater toxicity a pH of 5 was used here.

Table 9 Soil characteristics for New Zealand reference soils adjusted for use in normalisation equations

Soil property	Sensitive soil (Recent soil)	Typical soil (Brown soil)	Tolerant soil (Allophanic soil)
pH (CaCl2)	4.5	4.8	4.9
Clay (%)	17	21	23
CEC (cmol/kg)	15	19.5	30.1
Org. Carbon (%)	3.1	4.6	9.4

Note: CEC = cation exchange capacity

3.2.6 Statistical methods

The method used to derive Eco-SGVs depends on the number of species and taxonomic groups for which there are toxicity data (Table 10). A summary of the different taxonomic groups and microbial functional groups is shown in Tables 11 and 12. If sufficient data are available, the preferred methodology is the use of a species sensitivity distribution (SSD) as this is a risk-based approach. Where insufficient data are available the assessment factor approach should be used, noting this also has minimum data requirements (Table 10).

Table 10 Number of species or functional processes and number of taxonomic groups or nutrient groups needed for the species sensitivity distribution (SSD) and assessment factor (AF) approaches and the corresponding level of protection provided for residential land (NEPC 2013a)

Number of species or functional processes	Number of taxonomic or nutrient groups	Methodology to derive Eco-SGV
≥9	≥3	SSD
5–8	≥3	SSD
3–8	<3	AF

Table 11 The taxonomic groups for terrestrial species (NEPC 2013a)

Taxonomic group	Examples of species in this group
Mollusca	Snails, slugs
Annelida	Enchytraeids, earthworms
Nematoda	Nematodes
Hexapoda	Insects, springtails
Myriapoda	Centipedes, millipedes
Chelicerata	Mites, spiders
Crustaceans	Woodlice
Algae	Algae
Plantae	Plants
Fungi	Fungi
Bacteria	Bacteria
Protozoa	Amoebas, ciliates, flagellates
Tardigrada	Water bears
Chordata	Reptiles, mammals, birds

Table 12 The nutrient groups for soil (i.e. microbial and fungal) processes (NEPC 2013a)

Nutrient group	Soil process	Examples of end points
C cycle	Aerobic decomposition	Basal respiration, substrate-induced respiration
N cycle	N mineralisation/ammonification	Urease activity, NH_4 production
	Nitrification	NO_3 production, substrate-induced respiration
	Denitrification	Nitrate reductase
	Nitrogen fixation	Nitrogenase activity
P cycle	P mineralisation	Phosphatase, Py-phosphatase
S cycle	S mineralisation	Aryl-sulfatase

3.2.7 Calculation of the added contaminant limit using a species sensitivity distribution approach

The SSD approach is a statistical method to calculate a soil concentration that theoretically protects a specified percentage of species and/or soil processes. Discussion on the various approaches used to determine the SSD is provided in NEPC 2013a. The SSD method used to derive the Australian and New Zealand WQGs (ANZECC & ARMCANZ 2000) was the Burr Type III method, which was incorporated into the BurrliOZ program (Campbell et al. 2000). BurrliOZ is available from https://research.csiro.au/software/burrlioz/, and was used to derive added contaminant limits (ACL) in this report. Different statistical methods have been used to determine the SSD in the BurrliOZ programme; the selection of statistical

method is dependent on the data available and is made automatically within the programme.

Where normalised toxicity data is used, SSD methods use a single numerical value to describe each species or microbial process for which toxicity data is available, obtained as follows:

- If there was only one toxicity datum, that was taken to represent the species.
- If there were several toxicity values for the same end point, the geometric mean of the values was calculated and was taken to represent the species.
- If there were several toxicity values for different end points (e.g. mortality or reproduction), the end point with the lowest geometric mean was taken to represent the species.

Where toxicity data cannot be normalised, all screened data were retained to more adequately represent the variation in toxicity that is associated with variation in soil properties. However, the geomean was calculated for tests that were conducted for the same species using the same soil under the same conditions. Geomeans were not calculated for microbial processes, as different soils effectively represent different microbial communities, which may therefore respond differently. Similarly, data for different microbial endpoints from the same soil were retained as there is no evidence that one process is more sensitive than another.

This approach is consistent with that used in NEPC (2013a) and with recent OECD guidance on incorporating bioavailability into the derivation of soil threshold values (OECD 2017) It should be noted that the utilisation of multiple datapoints for a given species gives less clear assessment of the percentage of species protected, but it provide a greater representation of the influence of soil properties on toxicity for contaminants where normalisation relationships were not available.

If one taxonomic group is observed to be more sensitive than the others, the toxicity data belonging to the most sensitive distribution should be used for ACL derivation (NEPC 2013a).

3.2.8 Calculation of the added contaminant level using an assessment factor approach

If the minimum data requirements for the SSD approach cannot be met, the AF approach should be used to derive EILs. The AF is a 'worst-case scenario' approach. In this approach, the lowest toxicity value for a contaminant (i.e. the most sensitive data point) is divided by an AF to derive an ACL. The general equation is:

$$ACL = \frac{lowest\ NOEC(LOEC)\ or\ EC10(EC30)}{Assessment\ \ factor}$$

The magnitudes of the AFs depend on the available toxicity data and are given in Table 13.

Table 13 Assessment factors to be used to derive added contaminant limit (ACL) using the assessment factor (AF) approach (NEPC 2013)

Toxicity data available for derivation of ACL		
Number of species	**Number of taxonomic or nutrient groups**	**Assessment factor**
<3 species	N/A	500
≥3 species	1	100
	2	50
<5 species	3	10

N/A = not applicable

3.2.9 Livestock

The primary focus for the derivation of Eco-SGVs is on toxicity to soil microbes, plants and soil invertebrates. Additional consideration was given to the potential exposure of livestock to contaminants via soil ingestion. Copper and fluoride were the main focus, as livestock poisoning from excess exposure to these elements has been known to occur.

3.2.10 Accounting for secondary poisoning and biomagnification

Secondary poisoning can occur if contaminants accumulate from the ambient environment (e.g. soil) into the tissue of organisms that are then consumed by other organisms, and the concentration in tissue increases in the journey up the food chain (e.g. soil, earthworms, birds and predatory birds). In such a situation, the species at most risk are the species higher in the food web (the predators). Biomagnification and secondary poisoning should only be addressed for contaminants that show biomagnification potential.

Secondary poisoning should be addressed for land uses that cover large areas and can harbour many birds and small land species – this includes residential and recreational land use and agricultural land. Following Heemsbergen et al. (2009), the minimum land area to account for biomagnification is 250 m^2 for all land use excluding commercial/industrial land use. For commercial/industrial land use biomagnification should be considered if the surface under consideration is greater than 1000 m^2 unless the commercial land use is adjacent to an ecologically sensitive area. In this case, the trigger would be 250 m^2.

Secondary poisoning is taken into account in the soil quality guidelines of several countries, including Canada (CCME 2006) and USA (US EPA 2007a). The approach adopted here to address secondary poisoning is that used by NEPC (2013a), which in turn is consistent with the approach used in the Australian and New Zealand WQGs (ANZECC & ARMCANZ 2000). This approach increases the level of protection (i.e the percentage of species and/or soil processes to be protected) by 5% (i.e. to 85% from 80%). It is a pragmatic approach but not necessarily scientifically rigorous, and may result in values that are under- or over-protective. However, this approach recognises the paucity of New

Zealand data available to use a food-web approach, which is often used internationally (e.g. US EPA 2007; EC 2007; LDAI 2008; Ford and Beyer 2014).

Food-web approaches require a lot of data, including toxicity data for top predators, biomagnification and bioaccumulation data, and dietary information for the species of interest. While there is a paucity of New Zealand data, New Zealand has a comparatively simple food-web, with wildlife receptors being mainly birds; small mammals such as rabbits, stoats and possums may be present although these are considered pests and are not a focus for protection, other than being a potential food source for predatory birds (e.g. Australasian harrier, moreporks). In urban and urban/rural areas common birds are pūkekos, paradise shelducks, mallards and silvereyes, with tūī also common in some regions. Pūkekos, paradise shelducks and mallards are primarily vegetarian, with animal foods (aquatic and terrestrial insects) making up a small proportion of the diet. All three birds eat the stems, shoots, leaves and seeds of grasses, rushes, clover with paradise shelducks preferring pasture grasses. Pūkekos may also eat garden vegetables and crop plants. Robins are the only native birds that feed predominantly on soil invertebrates, although these are rarely seen outside native forest areas. Silvereyes feed predominantly on insects, such as aphids, caterpillars and flies, also spiders, as well as a range of small and large fruits and nectar from native and exotic vegetation. Tūī feed predominantly on nectar from native plans, with large invertebrates, such as cicadas and stick insects, also forming part of their diet in autumn.

Predatory birds are often considered as sentinels for environmental contamination. In New Zealand rural areas, the Australasian harrier (*Circus approximans*) is common and feeds on small live prey and carrion. Live prey includes small- to medium-sized birds and mammals, insects, lizards and frogs. Road-kill carrion can make up a large proportion of the diet (e.g. possum, rabbit and hedgehog), especially during winter when other food sources are limited. Moreporks may also be present in rural areas, and catch and consume a wide variety of small animals, including large insects, small birds (especially silvereyes), and small mammals.

From a very general perspective, the low contribution that worms, which are classically considered to bioaccumulate contaminants, make to the diet of key New Zealand wildlife receptors, and the typically low plant uptake of contaminants, suggests a generally low biomagnification or secondary poisoning risk in New Zealand terrestrial food webs. However, a recent study found that the DDTs in Australasian harriers was high compared to international studies, despite generally low environmental concentrations (Cavanagh et al. 2015), suggesting this may not always be the case.

3.2.11 Calculation of the background concentrations

The 'added-risk' approach requires the addition of the ACL to the background soil concentration as the final step in the development of Eco-SGVs. This allows for regional variation in background soil concentrations, and ensures that derived values are never lower than background. A separate report details the determination of background soil concentrations across New Zealand (Cavanagh et al. 2015). Existing data, primarily sourced from regional councils, was used to examine the relationship of trace element concentration (As, Cd, Cr, Cu, Pb, Ni, Zn) with a geological unit classification, Chemical4,

originating from GNS Science's QMAP 1:250 000 Geological Map of New Zealand GIS dataset (Heron 2014). Chemical4 is based on the QMAP ROCK_GROUP classification but further subdivides some on an age basis (i.e. older sedimentary rocks from their Miocene and younger rock and sediment equivalents, Maui and Pakihi supergroups) (Mortimer et al. 2014). Chemical4 provided the best fit for the combined data and was used to generate predicted background concentration distribution (described by the effective median, 5th and 95th percentile estimates) for the individual trace elements for the individual Chemical4 subgroups. Predictions for Chemical4 subgroups with few underlying samples ($n < 30$) are considered less reliable, and for $n < 10$, unreliable. In addition, areas that may have naturally occurring high concentrations of trace elements were identified through data retrieved from the New Zealand Petroleum & Minerals (NZP&M) Open File Metallic Minerals Geochemical Database (Crown Minerals 2009) and the Petlab Geoanalytical Database hosted by GNS Science (http://pet.gns.cri.nz). These data are presented as maps to illustrate currently identified areas of elevated concentrations in relation to the spatial distribution of soil samples in Cavanagh et al. (2015).

The concentrations provided in (Cavanagh et al 2015) are effectively the naturally occurring concentrations, as the premise of the analysis is that background soil concentration is influenced by the underlying geology. Naturally occurring background differs from ambient concentrations, which arise from diffuse or non-point sources by general anthropogenic activity not attributed to industrial or commercial land use. While ambient background concentrations are preferred for the development of Eco-SGVs, particularly in urban areas, these must be determined on the basis of measured concentrations. Currently there are insufficient data to robustly determine ambient concentrations of contaminants of concern across New Zealand.

With respect to deriving Eco-SGVs, the median, rather than 95th percentile is proposed for use as the background concentration – consistent with NEPC (2013a). The specific background concentrations to be used are dependent on location, and can be obtained from https://lris.scinfo.org.nz/. A summary of the range in concentrations is given in Table 14, with more details in Appendix A.

Table 14 Summary of the range in median and 95th percentile background trace element concentrations for geological groupings with n > 30 (see also Appendix A).

Trace element	Median range (mg/kg)		95th percentile range (mg/kg)	
As	2.1	4.1	8.9	17
Cd	0.05	0.10	0.05	0.49
Cu	6.7	25	29	108
Cr	8.6	27	41	129
Pb	6.8	16	25	56
Ni	4.4	14	25	77
Zn	25	44	102	183

Most organic contaminants of interest for the management of contaminated land are xenobiotics, hence they have no natural background concentration. An exception is the polycyclic aromatic hydrocarbons (PAHs), which may naturally occur through bushfires as well as occurring naturally in coal, crude oil and fuel. Cavanagh et al. (2016) collated existing data on PAHs and DDTs and provide preliminary estimates of ambient PAH concentrations in urban areas. While the widespread historical usage of DDT on pastoral land can be said to have given rise to an ambient concentration of DDT and its metabolites, the concentration at a given location is inherently dependent on historical usage at that location and so is too variable to provide an estimate of ambient concentrations. Eco-SGVs for DDT are anticipated to provide a more useful point of comparison to determine whether any action should be undertaken.

3.2.12 Calculation of the Eco-SGV

If biomagnification is not considered, the EIL for a contaminant is calculated as follows:

$$\text{Eco-SGV} = \text{ABC} + \text{ACL} \quad (2)$$

where ABC is the ambient background concentration (mg/kg) and ACL is the added contaminant limit (mg/kg).

If biomagnification is considered and is significant for that contaminant, the EIL is calculated as follows:

$$\text{Eco-SGV} = \text{ABC} + \text{ACL}_{BM} \quad (3)$$

where ACL_{BM} is the contaminant added limit that accounts for biomagnification.

To facilitate ease of reading and use, the final Eco-SGVs were rounded using the following scheme:

- all values <2 were rounded off to the nearest 0.1
- all values between 2 and 10 were rounded off to the nearest whole number
- all values between 10 and 100 were rounded off to the nearest multiple of 5
- all values between 100 and 1000 were rounded off to the nearest multiple of 10

3.2.13 Reliability of the derived Eco-SGVs

The level of confidence that can be placed in an Eco-SGV will depend on a number of factors, in particular data availability, and the ability to account for the influence of soil properties on observed toxicity. Eco-SGVs derived using the SSD approach and normalised toxicity data are considered to be highly reliable. If there are more than 10 datapoints available for use, the SSD approach can be used but toxicity data cannot be normalised for soil properties; the Eco-SGVs are considered to be of moderate reliability. If there are less than 10 datapoints available to generate Eco-SGVs using the SSD approach, or Eco-SGvs have been derived using the assessment factor approach, they are considered to be of low reliability.

4 Eco-SGVs for individual contaminants

4.1 Arsenic

The metalloid As occurs in a number of oxidation states, with AsV being the dominant form in oxidised soils and AsIII the dominant form under reducing conditions. Eco-SGVs are developed for AsV only.

4.1.1 Toxicity data

Data on chronic single-species toxicity tests for plants, invertebrates and microbial studies are summarised in Appendix B. To maximise the use of existing data, conversion factors (Table 4) were used to convert data into different endpoints. For plants, aged LOEC/EC30 in 21 species of plants ranged from 10 mg/kg for *Phaseolus vulgaris* and *Spinacia oleracea* to 2500 mg/kg in *Sorghum bicolour* (Appendix B). Plant toxicity data included only agricultural species, so all data were used to determine protection of agricultural land use. For invertebrates, given the limited amount of toxicity data available, some mortality data was used for some species for which no other data was available and the levels of effect were within the range of sub-lethal endpoints for other species. These data were divided by a nominal acute to chronic conversion factor of 5 reflecting the greater severity of this endpoint. In seven species of invertebrates aged LOEC/EC30s in different soils ranged from 5 mg/kg for reproduction in *Folsomia candida* to 2000 mg/kg for the growth of *Porcello scaber* (Appendix B). The aged LOEC/EC30s of As for *Folsomia candida* is based on the derived EC20 from the original study (Crouau et al. 2005) and is markedly lower than that for other soil invertebrates (Appendix B). This is the only study on the toxicity of As to *Folsomia candida* and appears to be robust so there is no reason to exclude this data point from ACL derivation. Tests on microbial processes are multi-species tests, in which the native soil microbial community is exposed. The selected LOEC/EC30 values comprise functional parameters including enzymatic activities (n = 14), and range from 749 mg/kg for N-mineralisation to 18 750 mg/kg for nitification activity in different soils. The functional parameters are based on the nitrogen cycle (n = 6), phosphorus cycle (n = 4) and sulphur cycle (n = 4).

Toxicity data were typically presented in terms of added concentration and so were used without further modification. Arsenic does not biomagnify, so the protection level for non-biomagnifying contaminants was used to generate the ACL for each land use.

4.1.2 Ageing leaching factor

NEPC (2013a) used an ALF factor of 2 to conservatively account for ageing in the derivation of aged ACLs. This is the lowest factor determined by Song et al. (2006) who assessed the effect of ageing As over three months in four soils. They found that in all soils the toxicity and extractability decreased and the extent of the decrease ranged from 2- to 12-fold with the extent of ageing significantly correlated with oxalate-extractable iron and Olsen-P concentrations (Song et al. 2006). Similarly, Yang et al. (2002) and Fendorf et al. (2004) also found that As aged in soils with most ageing occurring within the first few

months. However, Yang et al. (2002) also found that As ageing did not always occur – it occurred in only 47% (i.e. 17 out of 36) of the soils they examined.

No other relevant data were found, thus this ALF is used to derive ACL in the current study.

4.1.3 Normalisation relationships

Soil physicochemical properties affect the toxicity and bioavailabiity of As (e.g. Romero-Freire et al. 2015). Normalisation relationships for As toxicity were developed by Song et al. (2006), Cao et al, (2009a) and Anderson and Basta (2009). Song et al. (2006) related the toxicity of As (i.e. barley root elongation) to soil properties such as oxalate-extractable Mn and oxalate-extractable Fe concentrations. Cao et al. (2009a) found that content of ammonium oxalate extractable-Fe (Fe-ox) was the major soil property that had a strong relationship with the EC50 and EC10 values, while other properties, such as pH and $CaCO_3$ content, were unrelated to As toxicity. Anderson and Basta (2009) also found that iron oxides and pH explained variation. However, all normalisation relationships use soil properties that are typically not measured in toxicity studies. Therefore, normalisation relationships could not be used.

4.1.4 Derivation of ACL

There were 84 datapoints for 21 plant species, 7 species of invertebrate and 6 microbial processes, including 3 enzymatic processes (Figure 3, Appendix B) meeting the minimum requirements for the use of SSD to derive ACLs. The sensitivities of the different organisms were overlapping, hence all data were used to derive ACLs.

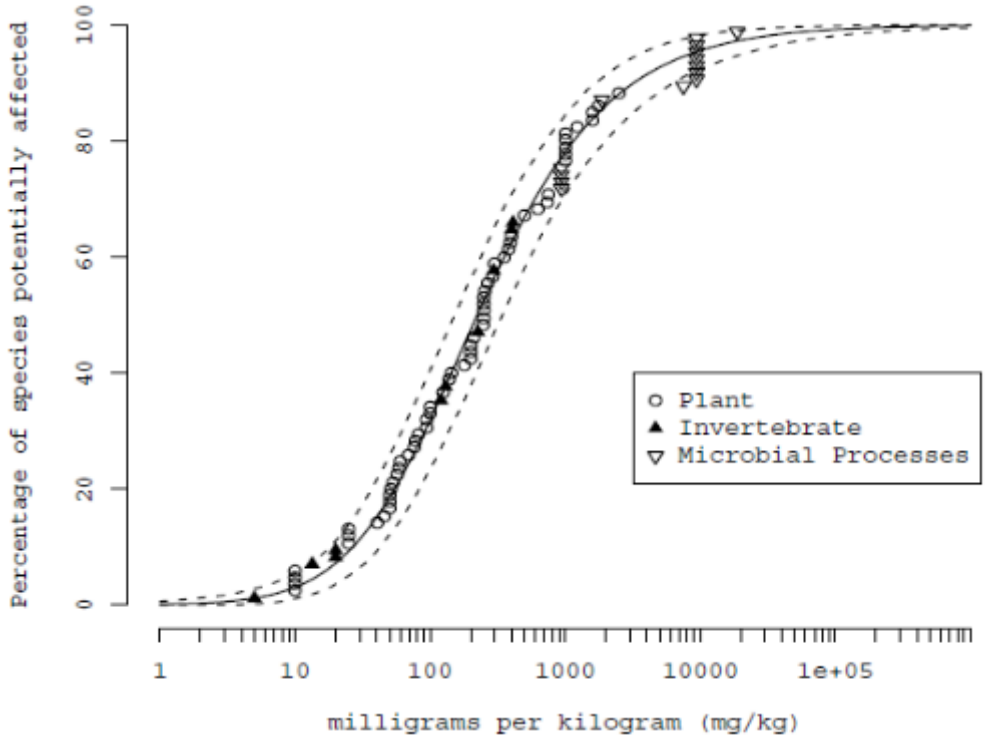

Figure 3 The SSD of 30% effect concentration (EC30) toxicity data for aged arsenic contamination for terrestrial plants, invertebrates and soil microbial processes.

As toxicity data were not able to be normalised to the New Zealand reference soils, a generic ACL for each land use was derived (Table 15) and applies to all New Zealand soils of the appropriate land use. For agricultural land, the ACL derived for protection of 95% of plant species is lower than that for protection of 80% of soil processes and invertebrates, thus the agricultural value is based on protection of plant species.

Only one study indicated toxicity occurring below the most protective ACL; this was toxicity As to *Folsomia candida* (Croau et al. 2005), which appears to be markedly more sensitive to As than other invertebrates. Some studies report toxicity to plants occurring at concentrations lower than the ACLs for non-food production land, agricultural land, and residential/recreational land use. This is partly indicative of the lower protection level afforded by these ACLs (particularly residential). These studies are based on freshly spiked soils, which, despite allowing for consideration of ageing, may still overestimate toxicity for aged contamination.

Table 15 Derived added concentration limits (ACL) and 95% confidence intervals for arsenic based on NOEC/EC10 and LOEC/EC30 toxicity endpoints

Land use	ACL $_{(EC10)}$ (mg/kg)	ACL $_{(EC10)}$ (mg/kg) (95% CI)	ACL$_{(EC30)}$ (mg/kg)	ACL $_{(EC30)}$ (mg/kg) (95% CI)
Areas of ecological significance	0.65	0.035 – 5.7	4.5	1.7 – 11
Non-food production land	4.3	1.1 – 14	15	9.2 – 26
Agricultural land (Plants)	6	3.6 – 9.8	16	7.4 – 30
Agricultural land (Soil process and invertebrates)	42	11 – 142	185	49 – 348
Residential/recreational area	24	11 – 54	55	36 – 85
Commercial/industrial	69	33 – 139	144	95 – 232

4.1.5 Derived Eco-SGVs

Median background concentrations of As determined for geological groupings with n >30 ranged from 2.1 to 4.1 mg/kg (Appendix A). This provides Eco-SGVs ranging from 6 mg/kg for areas of ecological significance to 150 mg/kg for commercial/industrial land (Table 16). The specific background concentrations to be used are dependent on location, and can be obtained from https://lris.scinfo.org.nz/. As the ACL for areas of ecological significance is comparatively low, the Eco-SGVs may be lower than the 95% percentile background concentrations (Table 16); the background concentrations used should be determined at the site of interest.

As the toxicity data were not able to be normalised, the derived Eco-SGVs are considered to be of moderate reliability.

Table 16 Summary of derived added contaminant limits (ACL), Eco-SGVs for arsenic, with the range in 95th percentile background concentrations shown for comparison

Land use	$ACL_{(EC30)}$ (mg/kg)	Median background concentration range (mg/kg)	Eco-SGV[1] $_{(EC30)}$ (mg/kg)	95th background concentration range (mg/kg)
Areas of ecological significance	4.5	2 – 4	6 – 8	9 – 17
Non-food production land	15		20	
Agricultural land	16		20	
Residential/recreational area	55		60	
Commercial/industrial	144		150	

[1]Values have been rounded; final Eco-SGVs should be based on background concentrations relevant to the site under assessment. Current estimates can be obtained from https://lris.scinfo.org.nz/.

4.1.6 Comparison with other guidelines

A compilation of SQGs for As from a number of jurisdictions is presented in Table 17. The derived Eco-SGVs are lower than the EILs derived for aged contamination for the equivalent land use in Australia, despite the similarity in methods. This difference arises largely from the selection of different toxicity data. For example, toxicity data older than 1970 and for terrestrial vertebrates were excluded from the Eco-SGV data compilation. The latter were excluded as it could not be verified that arsenic contaminated soil was the source of exposure in the toxicity studies (intake based on diet will be variable and dependent on As soil concentrations). The Eco-SGVs for non-food production land and agricultural land are similar to the Canadian SQGs for soil contact for agricultural and residential land-use and the US Eco-SSL for plants. The urban residential Eco-SGV is higher than the equivalent Canadian value, and similar to the US Eco-SSL for protection of birds and mammals.

Table 17 Soil quality guidelines for arsenic (As) from international jurisdictions

Jurisdiction	Name of value	Numerical value (mg/kg)		Source
New Zealand	Soil limit	20		NZWWA 2003
Australia	EILs	Fresh	Aged	NEPC 2013b
	Areas of ecological significance	20	40	
	Urban residential/public open space	50	100	
	Commercial/industrial	80	160	
Canada	SQG-soil contact Agricultural/residential	17		Environment Canada 1999a
	SQG-soil contact Commercial/industrial	26		
US	Eco-SSL plants	18		US EPA 2005a
	Eco-SSL invertebrates	NA		
	Eco-SSL avian	43		
	Eco-SSL mammalian	46		
Denmark	Ecotoxicological soil quality criteria	10		Carlon 2007

4.2 Boron

4.2.1 Toxicity data

Boron (B) is an essential element for plant growth and boron deficiency is common on a worldwide scale (Nable et al. 1997; Camacho-Cristobel et al. 2008). There is a narrow and overlapping concentration range of essentiality and toxicity with optimal boron for one species potentially toxic or insufficient for other species (Nable et al. 1997; Blevins & Lukaszewski 1998). Further, different genotypes of a given species exhibit different tolerances to B (e.g. Kaur et al. 2006, Cartwright et al. 1986. The greatest focus has been on the phytotoxicity of boron, although some recent studies have also investigated toxicity to soil invertebrates (e.g. Kaur et al. 2006, Becker et al. 2011).

Data on chronic single-species toxicity tests of B to plants, invertebrates and microbial studies are summarised in Appendix C. To maximise the use of existing data, conversion factors (Table 4) were used to convert data into different endpoints.

For plants, LOEC/EC30 in nine species of plants ranged from 3.5 mg/kg for *Hordeum vulgare* to 154 mg/kg for *Avena sativa* (Appendix C). Plant toxicity data included only agricultural crops, which were used to derive the ACL for agricultural plant species. In 12 species of invertebrates LOEC/EC30s in different soils ranged from 12 mg/kg for reproduction in *Eisenia andrei* to 373 mg/kg for reproduction of *Caenorhabditis elegans*. Three studies on microbial processes (enzymes) were found.

Boron toxicity studies report concentrations in different ways. For example, Becker et al. (2011) report toxicity on the basis of mg boric acid/kg soil, Kaur et al. (2006) report on the basis of hot $CaCl_2$ extractable, while Mertens et al. (2011) report on the basis of added B. For derivation of ACLs all toxicity was reported as added B, with $CaCl_2$ extractable B considered to be equivalent to added B. Toxicity data were typically presented in terms of added concentration and so were used without further modification. Boron doesn't biomagnify through the food chain, so the protection level for non-biomagnifying contaminants was used to generate the ACL for each land use.

4.2.2 Ageing and normalisation

There was no evidence that ageing reduced the toxicity of B to barley grown in 17 soils that had been freshly spiked and aged for 1 and 5 months (Mertens et al. 2010); therefore, an ageing/leaching factor of 1 is used here. Mertens et al. (2010) also found that B concentrations in soil solution provided the best measure of toxicity, but there was no relationship with soil properties other than soil moisture. Given the absence of a relationship of toxicity to soil properties, no normalisation relationships are applied to the B toxicity data.

4.2.3 Derived ACLs

There were 48 datapoints for 9 plant species, 13 invertebrate species and three microbial process (Figure 4; Appendix C) meeting the minimum requirements for the use of SSD to derive ACLs. The sensitivities of the plants and invertebrates were overlapping, with

microbial processes generally being less sensitive. Given the limited amount of data for toxicity to microbes, all data were used to derive ACLs.

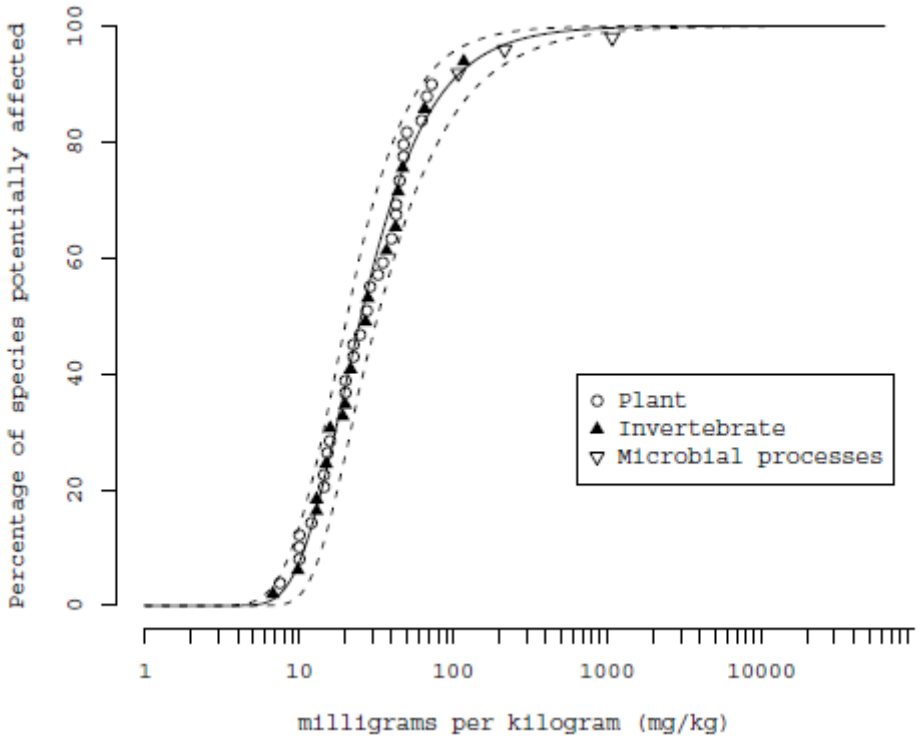

Figure 4 The SSD of 30% effect concentration (EC30) toxicity data for boron contamination for terrestrial plants, invertebrates and soil microbial processes.

As toxicity data were not able to be normalised to the New Zealand reference soils, a generic ACL for each land use was derived (Table 18) and applies to all New Zealand soils of the appropriate land use. For agricultural land, the ACL derived for protection of 95% of plant species is lower than that for protection of 80% of soil processes and invertebrates, thus the agricultural value is based on protection of plant species.

Table 18 Added concentration limits (ACL) developed for B, based on NOEC/EC10 and LOEC/EC30 toxicity endpoints

Land use	ACL $_{(EC10)}$ (95% CI) (mg/kg)	ACL$_{(EC30)}$ (95% CI) (mg/kg)
Areas of ecological significance	3.0 (1.6 – 3.9)	5.8 (2.3 –9.3)
Non-food production land	4.2 (3.4 – 5.3)	9.7 (6.7 –13)
Agricultural land (Plants)	3.3 (2.1 – 5.6)	8.0 (4.5 –12)
Agricultural land (Soil process and invertebrates)	8.8 (6.6 – 13)	14 (11 –21)
Residential/recreational area	6.6 (5.6 – 8.6)	17 (13 –22)
Commercial/industrial	10 (8.7 – 13.9)	21 (17 – 26)

4.2.4 Derived Eco-SGVs

The toxicity of B is often expressed simply as the concentration of spiked B while there are various methods to analyse soil B. In New Zealand B is ypically measured using either acid extraction or hot water solubility, which is commonly used to assess B deficiency. Given the common use of hot-water soluble B for contaminated land assessments, arising from previously established guideline values (MFE 2011) further investigation was undertaken to determine if EcSGVs could be established on the basis of hot-water soluble B. AEP (2016) found a good relationship between hot-water soluble B (HWS B) and spiked B for two agricultural soils (equations 4 and 5), although B measured as a saturated paste actually provided a better measure of toxicity in different soils. Given the common use of hot-water soluble B for contaminated land assessments, equations 4 and 5 were used to express derived ACLs as hot-water soluble B concentrations. Specifically, these relationships were combined into equation 6, given the closeness of the relationships in the different soils, which was used to derive the HWS ACLs. The contribution of HWS-B from background concentrations is expected to be negligible (AEP 2016), thus the HWS B ACLs can be used directly as the Eco-SGVs. However, it is noted that the typical range of HWS B in agricultural soils, which may have boron added as a fertiliser, is 1 – 3 mg/kg.

HWS B (mg/kg) = 0.8732B + 1.3871 R^2 = 0.9979 (4)

HWS B (mg/kg) = 0.8932B - 2.6223 R^2 = 0.9981 (5)

Where B = spiked B concentrations (mg/kg)HWS B (mg/kg) = 0.0.8732B + 1.3871 (6)

Table 19 Eco-SGVs for boron based on LOEC/EC30 ACLs expressed as hot-water soluble B concentrations

Land use	$ACL_{(EC30)}$ (mg/kg)	HWS $ACL_{(EC30)}$(mg/kg)	Eco-SGV[1]$_{(EC30}$
Areas of ecological significance	5.8	3.9	50[2]
Non-food production land	9.7	7.3	7
Agricultural land	8.0	5.8	6
Residential/ recreational areas	17	13.8	15
Commercial/industrial	21	17.3	15

[1]Values have been rounded; based on hot-water soluble B concentrations; contribution of background HWS B is considered to be negligible.

4.2.5 Comparison to international values

There are limited SQGs for B to compare with the derived ACLs. The ACLs are slightly higher than the threshold for plant toxicity of 3 mg/kg also measured as hot water soluble B in the *Timber Treatment Guidelines* (MfE 2011). This value was sourced from the UK Interdepartmental Committee on the Redevelopment of Contaminated Land (ICRCL, exact reference not specified). Similarly, the ACLs for agricultural land are higher than Canadian SQGs for agriculture of 2 mg/kg (hot water soluble B) (CCME 2014). As noted above, more

recent Canadian guidance has provided SQGs expressed on the basis of saturated paste measures of B. These authors provide a boron SQG for soil contact for agricultural land use of 3.4 mg/L and for commercial/industrial land use, 8.7 mg/L. The relationship between saturated paste measures of B and hot-water soluble B varies markedly for different soil types, thus it is not possible to provide a direct-comparison of the values.

4.3 Cadmium

4.3.1 Toxicity data

Data on chronic single-species toxicity tests of Cd to plants, invertebrates and microbial studies are summarised in Appendix D. To maximise the use of existing data, conversion factors (Table 5) were used to convert data into different endpoints. For plants, LOEC/EC30 in 23 species of plants ranged from 1.5 mg/kg for *Glycine max* to 2130 mg/kg for *Triticum aestivum* (Appendix D). Plant toxicity data included only one non-agricultural crop, which was excluded from the derivation of the ACL for agricultural plant species. In 14 species of invertebrates LOEC/EC30s in different soils ranged from 10 mg/kg for reproduction in *Eisenia andrei* and *Dendrobaena rubida* cocoon reproduction to 461 mg/kg for survival of *Caenorhabditis elegans*. Tests on microbial processes are multi-species tests in which the native soil microbial community is exposed. The selected LOEC /EC30 values comprise functional parameters including enzymatic activities (n = 49), and microbial growth (n = 1). The functional parameters are based on the carbon cycle (n = 20), nitrogen cycle (n = 15), including denitrification and mineralisation of specific substrates, phosphorus cycle (n = 8) and sulphur cycle (n = 5).

Despite the vast number of studies on plants and Cd, almost all recent studies relate to determining the plant uptake of Cd and do not provide general toxicity measures suitable for the derivation of SGVs. Hence, underlying data are based on predominantly older toxicological data.

Toxicity data were typically presented in terms of added concentration and so were used without further modification. Cadmium does biomagnify through the food chain, so the protection level for biomagnifying contaminants was used to generate the ACL for each land use.

4.3.2 Ageing and leaching

Smolders et al. (2009) evaluated existing literature to assess the effects of ageing and leaching on the toxicity of Cd. These authors concluded that there was no observable effect of ageing or leaching and assigned an ageing/leaching factor of 1 for Cd. In contrast to the other trace elements examined by these authors, no new data to assess the effects of ageing and leaching were developed, and thus this represents a potential knowledge gap. In the absence of data to support the use of an ageing/leaching factor >1, an ageing/leaching factor of 1 is used in this work.

4.3.3 Normalisation

While a considerable number of studies have examined the relationship of plant uptake of Cd to soil properties, and show that pH in particular can influence uptake (higher uptake at lower pH), there are comparatively fewer assessing the influence of soil properties on Cd toxicity. Further, the EC (2007) observed that despite a significant number of experiments being conducted with Cd, toxicity varied considerably but not clearly in relation to soil properties. Hence normalisation of toxicity data to New Zealand reference soils was not undertaken.

4.3.4 Derived ACLs

There were 174 toxicity measures for 23 species of plants, 14 invertebrate species and 18 microbial processes, including 8 enzymatic processes, meeting the minimum requirements for the use of SSD to derive ACLs. The sensitivities of the different organisms were overlapping (Figure 5), hence all data were used to derive ACLs.

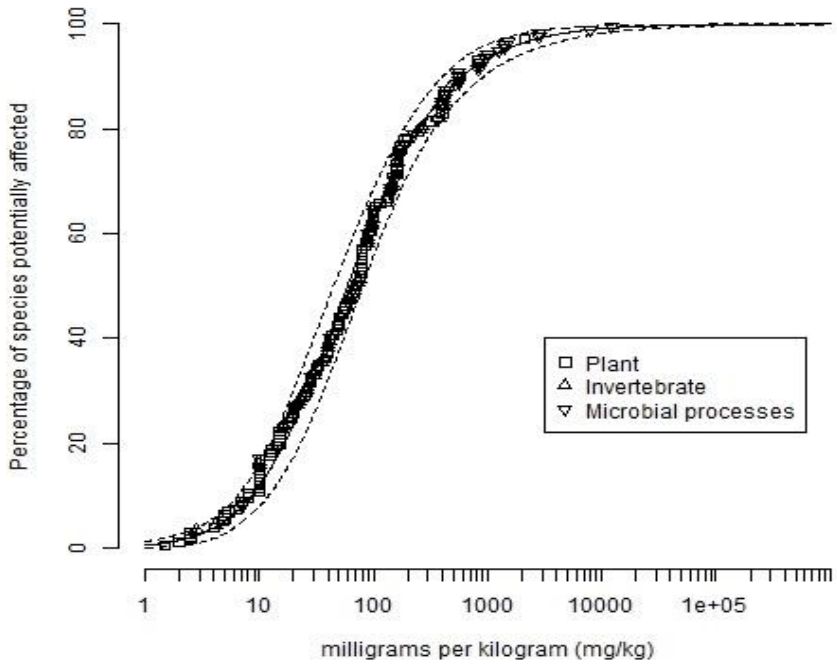

Figure 5 The SSD of 30% effect concentration (EC30) toxicity data for aged cadmium contamination for terrestrial plants, invertebrates and soil microbial processes.

As toxicity data were not able to be normalised to the New Zealand reference soils, a generic ACL for each land use was derived (Table 20) and applies to all New Zealand soils of the appropriate land use. For agricultural land, the ACL derived for protection of 95% of plant species is lower than for protection of 80% of invertebrate species and microbial processes; thus, the ACL for agricultural land was based on protection of plant species.

As Cd is known to biomagnify through the food chain, ACLs should be based on an increased level of protection for the different landuses (85% for residential/recreational areas, 65% for commercial/industrial areas).

No studies reported toxicity occurring below the most protective ACL (1.5 mg/kg), although some effects on plant growth and cocoon production in *Apporectodea caliginosa* were reported to occur at slightly higher concentrations, and below ACLs (non-biomagnifying) for non-food production land, agricultural land, and residential/recreational land use. This is largely indicative of the lower protection level afforded by these ACLs (particularly residential).

Table 20 Added concentration limits (ACLs), and 95% confidence intervals for ACLs, developed for cadmium, based on NOEC/EC10 and LOEC/EC30 toxicity endpoints

Land use	ACL $_{(EC10)}$ (95% CI) (mg/kg)	ACL$_{(EC30)}$ (95% CI) (mg/kg)
Areas of ecological significance	1.2 (0.7 – 1.9)	1.5 (0.7 – 2.8)
Non-food production land	2.9 (2.2 – 4 1)	4.8 (3.4 – 6.9)
Agricultural land (Plants)	2.2 (1.3 – 3.3)	3.1 (1.1 – 5.1)
Agricultural land (Soil process and invertebrates)	20 (13 – 30)	34 (23 – 51)
Residential/recreational area	8.7 (6.7 – 12)	17 (13 – 23)
Residential/recreational area - 85% Protection Level	6.7 (5.2-8.7)	12 (9.2 – 16.5)
Commercial/industrial	20 (16 – 28)	40 (29 – 50)
Commercial/industrial – 65% Protection Level	17(13 – 22)	33 (24 – 45)

4.3.5 Derived Eco-SGVs

Median background concentrations of Cd determined for geological groupings with n >30, ranged from 0.05 to 0.1 mg/kg (Appendix A). Thus, background concentrations make a negligible contribution to Eco-SGVs, and the derived ACLs effectively become the Eco-SGVs (Table 21). The specific background concentrations used are dependent on location, and can be obtained from https://lris.scinfo.org.nz/.

Table 21 Eco-SGVs for cadmium based on LOEC/EC30 ACLs, median and 95th percentile background concentrations shown for comparison

Land use	Eco-SGV[1] (mg/kg)	Eco-SGVBM[1] (mg/kg)	Range median background concentration (mg/kg)	Range 95th background concentrations (mg Cd/kg)
Areas of ecological significance	1.5	1.5		
Non-food production land	4.8	1.5		
Agricultural land	3.1	1.5	0.05 – 0.1	0.2 – 0.5
Residential/recreational areas	17	12		
Commercial/industrial	40	33		

[1]Values have been rounded; final Eco-SGVs should be based on background concentrations relevant to the site under assessment. Current estimates can be obtained from https://lris.scinfo.org.nz/. BM – protective of exposure via biomagnification.

4.3.6 Comparison to international values

A compilation of SQGs for Cd from a number of jurisdictions is presented in Table 22. The derived Eco-SGVs are higher than most SQGs accounting for biomagnification (PNEC-secondary poisoning, US Eco-SSLs for birds and terrestrial mammals), although lower than the Canadian SQG for soil and food ingestion that applies to agricultural land (Table 22). Eco-SGVs for urban residential/recreational areas and commercial/industrial areas are similar to the Canadian SQGs for the equivalent landuse, and lower than US Eco-SSLs for invertebrates.

Table 22 Soil quality guidelines (SQG) for cadmium from international jurisdictions; PNEC = Predicted No effect concentration, Eco-SSL =Ecological-soil screening level

Jurisdiction	Name of value	Numerical value (mg/kg)	Source
New Zealand	Biosolids	1	NZWWA 2003
Canada	SQG – soil and food ingestion Agricultural	3.8	Environment Canada 1999b
	SQG – soil contact agricultural/residential	10	
	SQG – soil contact commercial/industrial	22	
EU	PNEC – microbes, invertebrates and plants	1.5 – 2.3	EC 2007
	PNEC – secondary poisoning	0.9	
US	Eco-SSL plants	32	US EPA 2005b
	Eco-SSL invertebrates	140	
	Eco-SSL avian	0.77	
	Eco-SSL mammalian	0.36	
Denmark	Ecotoxicological soil quality criteria	0.3	Carlon 2007

4.4 Chromium

Chromium occurs in a number of oxidation states: II, III, IV, V and VI, although toxicity data are mostly available for Cr (III) or Cr (VI) species, while total chromium measured in the environment may be a mixture. However, Cr (III) is the dominant form in the environment, therefore, Eco-SGVs are developed for Cr (III). However, as Cr (VI) is more toxic than Cr (III) and may be present in fresh chromium contamination, toxicity of Cr(VI) should be evaluated.

4.4.1 Toxicity data

Data on chronic single-species toxicity tests for plants, invertebrates and microbial studies are summarised in Appendix E. To maximise the use of existing data, conversion factors (Table 5) were used to convert data into different endpoints. For plants, aged LOEC/EC30 in 11 species of plants ranged from 250 mg/kg for *Sorghum bicolour* to 12 500 mg/kg in *Agrostis tenuis* (Appendix E). There was one non-agricultural plant species; thus, toxicity data were available for 10 plant species for the development of ACLs for agricultural land

use. In four species of invertebrates aged LOEC/EC30s in different soils ranged from 250 mg/kg for cocoon production in *Eisneia andrei* to 2500 mg/kg for reproduction in the remaining species (Appendix E). Tests on microbial processes are multi-species tests, in which the native soil microbial community is exposed. The selected LOEC /EC30 values comprise 12 microbial processes, including seven enzymatic processes (n = 42), and range from 100 mg/kg for respiration to 3250 mg/kg for phosphatase activity in different soils. The functional parameters are based on the carbon cycle (n = 19), nitrogen cycle (n = 12), phosphorus cycle (n = 9) and sulphur cycle (n = 7). Toxicity data were available for the enzyme catalase although they were markedly lower (more than one order of magnitude) than all the other toxicity data. Given this and that the toxicity data were quantified using nominal (not measured) concentrations, these data were excluded because of their uncertainty.

Toxicity data were typically presented in terms of added concentration and so were used without further modification. Chromium III does not biomagnify, so the protection level for non-biomagnifying contaminants was used to generate the ACL for each land use.

4.4.2 Ageing and leaching factor

No data specifically for the effects of ageing and leaching on the toxicity of Cr (III) were found, although it is generally acknowledged that these factors will reduce toxicity. An ALF of 2.5 was used for Cr (III). This is the interim ALF used by NEPC (2013a) and is based on the rounded mean of the ALF values available for other cations (i.e. Cd, Cu, Co, Ni, Pb and Zn) from Smolders et al. (2009).

4.4.3 Normalisation relationships

Three normalisation relationships were available in the published literature. These relationships came from one study and were based on the toxicity of Cr III to the survival of the earthworm*, Eisenia fetida* (Sivakumar & Subbhuraam 2005):

EC_{50} = –5.46 clay content + 1905.93 (r^2 = 0.92)

EC_{50} = –5.75 clay content – 10.62 pH + 1980.46 (r^2 = 0.92)

EC_{50} = –3.59 clay content + 4.16 pH + 65.83 soil N + 1748.22 (r^2 = 0.95)

These relationships were based on soils with clay content ranging from 8.75% to 43%, and so are considered to be robust. Relationship a) was used to normalise toxicity for soft-bodied invertebrates but no other species or microbial processes.

4.4.4 Derived ACLs

There were 76 selected toxicity measures from 11 species of plants, 5 invertebrate species and 12 microbial processes, including 7 enzymatic processes, meeting the minimum requirements for the use of SSD to derive ACLs. The sensitivities of the different organisms were overlapping (Figure 6), hence all data were used to derive ACLs.

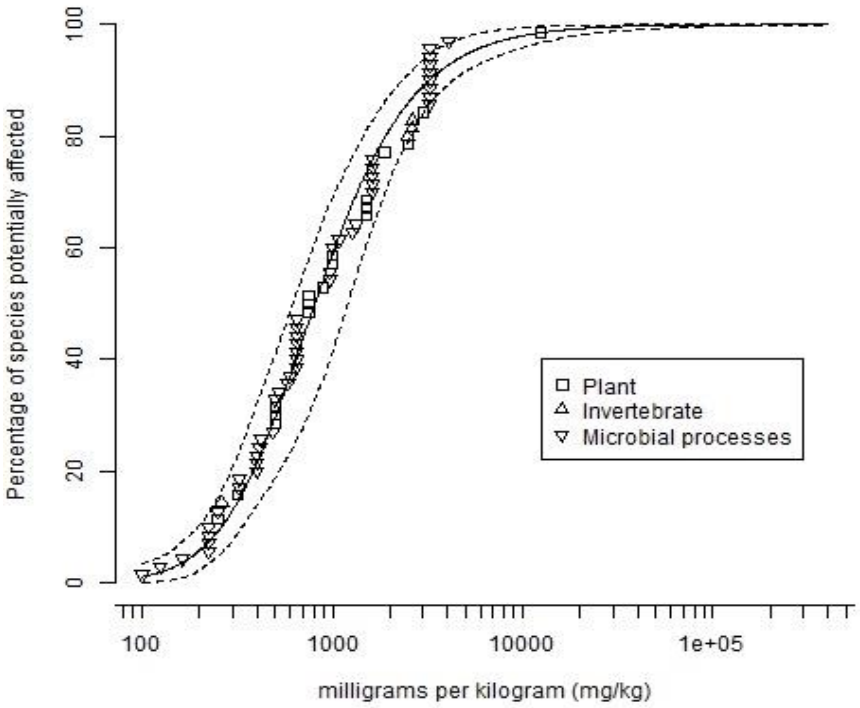

Figure 6 The SSD of 30% effect concentration (EC30) toxicity data for aged chromium contamination for terrestrial plants, invertebrates and soil microbial processes.

Only the Cr (III) toxicity data for *Eisenia fetida* and *E. andrei* could be normalised to the New Zealand reference soils, and ACLS developed for the three reference soils are shown in Tables 23 and 24. As the values vary only marginally, and when rounded are no different, only a single set of Eco-SGVs are developed. For agricultural land, the ACL derived for protection of 95% of plant species was lower than that for protection of 80% of invertebrate species and microbial processes; thus, the ACL for agricultural land was based on protection of plant species.

No studies reported toxicity occurring below the most protective ACL (92 mg/kg), although some effects on microbial activity were reported at slightly higher concentrations, and below ACLs for non-food production land, agricultural land, and residential/recreational land use. This is largely indicative of the lower protection level afforded by these ACLs (particularly residential).

Table 23 Added concentration limits (ACLs) for chromium based on aged NOEC/EC10 and LOEC/EC10 toxicity endpoints for a 'typical' New Zealand reference soil

Land use	ACL $_{(EC10)}$ (95% CI) (mg/kg)	ACL $_{(EC30)}$ (95% CI) (mg/kg)
Areas of ecological significance	22 (38 – 81)	96 (35 – 184)
Non-food production land	75 (41 – 128)	187 (123 – 265)
Agricultural land (Plants)	135 (56 – 356)	294 (165 – 515)
Agricultural land (Soil processes and invertebrates)	156 (115 – 219)	318 (254 – 487)
Residential/recreational	221 (148 – 305)	383 (291 – 489)
Commercial/industrial	412 (306 – 574)	642 (499 – 962)

Table 24 Added concentration limits (ACLs) for chromium based on aged LOEC/EC10 toxicity endpoints for 'sensitive' and tolerant New Zealand reference soils. Values were not calculated for agricultural land, given the similarity to other land uses

Land use	ACL $_{(EC30\ senstive)}$ (95% CI) (mg/kg)	ACL $_{(EC30\ tolerant)}$ (95% CI) (mg/kg)
Areas of ecological significance	92 (34 – 181)	97 (40 – 187
Non-food production land	184 (122 – 260)	188 (130 – 264)
Residential/recreational	382 (284 – 488)	384 (291 – 504)
Commercial/industrial	641 (494 – 899)	643 (498 – 976)

4.4.5 Background concentrations

Median background concentrations of Cr determined for geological groupings with n >30, (Appendix A) ranged from 8.6 to 26.6 mg/kg. This provides Eco-SGVs ranging from 100 mg/kg for areas of ecological significance to 670 mg/kg for commercial/industrial land (Table 25). The specific background concentrations used is dependent on the location under consideration, and can be obtained from https://lris.scinfo.org.nz/.

Table 25 Eco-SGVs for Cr (III), with the range in 95th percentile natural background concentrations shown for comparison

Land use	Eco-SGV[1] $_{(EC30)}$ (mg/kg)	95th percentile background concentrationrange (mg/kg)
Areas of ecological significance	100 – 120	
Non-food production land	190 – 210	
Agricultural land (Plants)	300 – 320	40 – 130
Residential/recreational	390 – 410	
Commercial/industrial	650 – 670	

[1]Values have been rounded; final Eco-SGVs should be based on background concentrations relevant to the site under assessment. Current estimates can be obtained from https://lris.scinfo.org.nz/.

4.4.6 Comparison with international values

A compilation of SQGs for Cr from a number of different sources is presented in Table 26. The majority of these SQGs are for total Cr, and so include consideration of the toxicity associated with Cr (VI), which is more toxic than Cr (III). However, the derived Eco-SGVs are similar to the EILs derived for aged Cr (III) contamination in the equivalent land use in Australia, and tend to be higher than most international SQGs. The Eco-SGVs are below the soil limit for biosolid application in NZWWA (2003).

Table 26 Soil quality guidelines for chromium from international jurisdictions

Jurisdiction	Name of value	Numerical value (mg/kg)		Source
New Zealand	Soil limit	600		NZWWA (2003)
Australia	Ecological investigation levels[1]	Fresh	Aged	NEPC (2013b)
	Areas of ecological significance	130	140	
	Urban residential/public open space	230	410	
	Commercial/industrial	340	670	
Canada	SQG-environment Agricultural/residential	64 (total)		Environment Canada 1999c
	SQG-environment Commercial/industrial	87 (total)		
US	Eco-SSL plants	Not enough data		US EPA 2008
	Eco-SSL invertebrates	Not enough data		
	Eco-SSL avian	26		
	Eco-SSL mammalian	34		
Denmark	Ecotoxicological soil quality criteria	50		Carlon 2007

[1]Derived using EIL-calculator for the Australian reference soil (10% clay)

4.5 Copper

4.5.1 Data compilation and screening

Data on chronic single-species toxicity tests for plants, invertebrates and microbial studies are summarised in Appendix F. To maximise the use of existing data, conversion factors (Table 5) were used to convert data into different endpoints, where needed. For plants, aged LOEC/EC30 in eight species of plants ranged from <20 mg/kg for *Lycopersicon esculentum* to 720 mg/kg also for *Lycopersicon esculentum* (Appendix F). Plant toxicity data included two non-agricultural species, which were excluded from the derivation of the ACL for agricultural plant species. In 14 species of invertebrates LOEC/EC30s in different soils ranged from 15 mg/kg for reproduction in *Eisenia andrei* and *Folsomia candida* to 3600 mg/kg for growth of *Porcello scaber*. Tests on microbial processes are multi-species tests in which the native soil microbial community is exposed. The selected LOEC /EC30 values comprise functional parameters including enzymatic activities (n = 90). The functional parameters are based on the carbon cycle (n = 49); nitrogen cycle (n = 30), including denitrification and mineralisation of specific substrates; phosphorus cycle (n = 6) and sulphur cycle (n = 5).

Toxicity data were typically presented in terms of added concentration and so were used without further modification. Cu does not biomagnify through the food chain, so the protection level for non-biomagnifying contaminants was used to generate the ACL for each land use.

4.5.2 Normalisation

NEPC (2013b) identified 18 normalisation relationships reported in the literature for Cu toxicity and derived two as part of their study. Six were developed for Australian soils (Broos et al. 2007; Warne et al. 2008a,b) and 14 have been derived for European soils (Oorts et al. 2006; Rooney et al. 2006; Criel et al. 2008; EC 2008. Eight of the relationships were for plants, six for soil invertebrates, and six for microbial functions. In addition, Li and Wang (2010) developed normalisation relationships for plants in Chinese soils.

The choice of normalisation relationships used to normalise the toxicity data was based on (1) regional relevance, (2) whether they are based on field- or laboratory-based toxicity data, with preference is given to field-based relationships, (3) whether they provide a conservative SQG – normalisation relationships with lower gradients will provide lower normalised toxicity values and thus lower SQGs (ECI 2008), (4) the quality of the relationship as indicated by the coefficient of determination (r^2), and (5) the number of species to which the relationships apply.

Appropriate Australian normalisation relationships were applied to Australian toxicity data and European and Chinese normalisation relationships were applied to European and Chinese toxicity data, respectively. The normalisation relationships used are shown in Table 27. Specifically, a field-based regression relationship for wheat was used to normalise all Australian plant toxicity data, while the regression relationship for all microbial processes was normalised using the normalisation relationship for SIN (substrate induced nitrification). For the European soils, the relationship for barley was used to normalise the data for all plants except tomatoes. The relationship for *Eisenia fetida* was used for all soft-bodied invertebrates, and that for *Folsomia candida* for hard-bodied invertebrates. These relationships are the same as those used in NEPC (2013b). For European microbial studies, the normalisation relationships used in ECI 2008 were used in this study (Table 27). Specifically, all toxicity data related to the N-cycle (i.e. N-mineralisation, nitrification, denitrifcation and ammonification) were normalised based on the CEC slope of the nitrifying micro-organisms (potential nitrification rate, PNR). The slopes obtained from the maize respiration model (MRM) were used for normalisation of all microbial processes data using a natural substrate. All other microbial processes data were normalised based on the regression slopes from the substrate induced respiration tests. Finally, Chinese regression relationships were used to normalise the Chinese plant toxicity data.

Table 27 Normalisation relationships used to normalise the toxicity of copper (Cu) to plants, soil invertebrates and soil processes (adapted from NEPC 2013b); OC = organic carbon; CEC = cation exchange capacity

Species/soil process	Y parameter	X parameter(s)	Reference
Australian relationships			
Triticum aestivum (wheat)	log EC_{10} (field-based grain yield)	0.31 pH[a] + 1.05 log OC + 0.56 (r^2 adj = 0.80)	Warne et al. 2008b
SIN[b]	log EC_{50}	0.35 pH[a] + 0.84 (r^2 adj = 0.72)	NEPC 2013b
European relationships			
Hordum vulgare (barley)	log EC_{50}	0.69 log CEC + 1.42 (r^2 = 0.66)	ECI 2008
Lycopersican esculentum (tomato)	log EC^{50}	0.96 log CEC + 1.47 (r^2 = 0.75)	ECI 2008
Eisenia fetida (earthworm)	log EC_{50}	0.58 log CEC + 1.85 (r^2 = 0.75)	ECI 2008
Folsomia candida (collembola)	log EC_{50}	0.96 log CEC + 1.63 (r^2 = 0.63)	ECI 2008
SIR[b]	log EC_{50}	0.73 log OC + 0.6 log clay (r^2 = 0.57)	ECI 2008
MRM[b]	log $EC5_0$	-0.34 pH + 0.72 log CEC 4.05 (r^2 = 0.71)	ECI 2008
PNR[b]	log EC_{50}	1.06 log CEC + 1.41 (r^2 = 0.66)	ECI 2008
Chinese relationship			
Hordum vulgare (barley)	log EC_{50}	0.197 pH + 0.956 log eCEC (r^2= 0.79)	Li and Wang 2010

a = pH measured in 0.01 M calcium chloride.

[b] SIN = Substrate induced nitrification; MRM = maize residue mineralisation; PNR = potential nitrification rate; SIR = substrate induced respiration.

4.5.3 Ageing and leaching factor

The European Copper Institute (ECI 2008) provides a comprehensive discussion of available data on the influence of ageing and leaching on toxicity of Cu. This included field contaminated soils and experimentally spiked and aged soils. A generic ALF of 2.0 was proposed, which was between the 10th to15th percentile of the field contaminated soils and about the 25th percentile of all individual factors (field aged and experimentally aged). This ALF was considered to apply to tests starting within 120 days after spiking to generate aged $NOEC_{add}$ values. For studies in which soils have been equilibrated for more than 120 days after spiking, the ALF factor is 1.0. This ALF is also described in Smolders et al. (2009), and used in NEPC (2013b), and is adopted for use in the current study.

4.5.4 Derived ACLs

There were 276 selected toxicity measures from eight species of plants, 16 invertebrate species and eight microbial processes, including four enzymatic processes, meeting the minimum requirements for the use of SSD to derive ACLs. As data were normalised to the New Zealand reference soils, the geometric mean was calculated for each plant and invertebrate species and each microbial process for use in the SSD. The sensitivities of the different organisms were overlapping (Figure 7), hence all data were used to derive ACLs. Copper present in urban stormwater that may be discharged to land is in a similar form to Cu solutions used to spike soils for toxicity testing. Added contaminant limits were derived for fresh and aged contamination for each of the three New Zealand reference soils (Tables 28 & 29). For agricultural land, the ACL derived for protection of 95% of plant is lower than that for protection of 80% of invertebrate species and microbial processes, thus the Eco-SGV for agricultural land was based on protection of plant species.

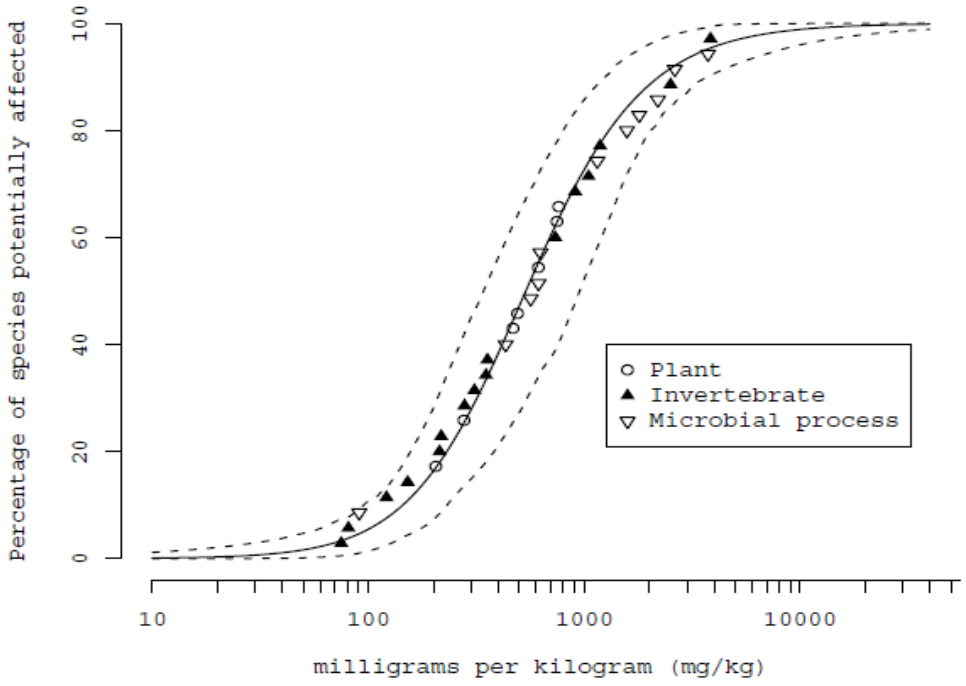

Figure 7 The SSD of 30% effect concentration (EC30) toxicity data for aged copper contamination for terrestrial plants, invertebrates and soil microbial processes.

The available toxicity data indicate that some microbial processes in Australian studies are negatively affected at concentrations lower than the most protective ACLs (4 mg/kg). Similarly, the lower ACLs for non-food production land (95% protection level) compared to agricultural land and residential land appear to be due to the sensitivity of microbial processes in some soils.

Table 28 Added concentration limits (ACL) derived for copper using LOEC/EC30 toxicological endpoints for fresh and aged contamination for the typical New Zealand reference soil

Land use	ACL (EC10 fresh) (95% CI) (mg/kg)	ACL (EC10 aged) (95% CI) (mg/kg)	ACL (EC30 fresh) (95% CI) (mg/kg)	ACL (EC30 aged) (95% CI) (mg/kg)
Areas of ecological significance	21	42	16	72
Non-food production land	34	69	39	108
Agricultural land (Plants)	46	136	70	218
Agricultural land (Soil processes and invertebrates)	52	150	79	220
Residential/recreational	47	141	103	197
Commercial/industrial	136	271	298	339

Table 29 Added concentration limits (ACL) derived for copper using LOEC/EC30 toxicological endpoints for aged contamination for the sensitive and tolerant New Zealand reference soils

Land use	ACL (EC30fresh) sensitive (mg/kg)	ACL (EC30aged) sensitive (mg/kg)	ACL (EC30fresh) Tolerant (mg/kg	ACL (EC30aged) Tolerant (mg/kg
Areas of ecological significance	15	30	35	70
Non-food production land	27	55	45	90
Agricultural land (Plants)	55	109	130	260
Residential/recreational	63	120	130	412
Commercial/industrial	131	250	350	600

4.5.5 Protection of livestock

Sheep are recognised to be more sensitive to copper poisoning than other livestock (Grace et al. 2011). However, it is also recognised that New Zealand livestock are generally deficient in copper, and copper supplementation is often required (Grace et al. 2011). Further, the toxicity of Cu is also dependent on concentration of molybdenum in pasture (Table 30). Thus, to determine whether the derived Eco-SGVs for agricultural land are protective of livestock requires additional research to assess uptake of Cu (and Mo) by pasture species in different soils. However, it is not expected that the Eco-SGVs will lead to copper poisoning in livestock.

Table 30 A guide to Cu and Mo concentrations in pastures and consequences for animal health (Grace et al. 2011)

Pasture Mo (mg/kg)	Pasture Cu (mg/kg DM) ACL (EC30aged) sensitive(mg/kg)		Consequences
	Sheep	Cattle	
0.5	3	3	Cu deficiency
1	5 – 6	9 – 10	Cu status adequate
2-3	5 – 6	9 – 10	Mo in excess, Cu status not adequate
2-3	9 – 10	18 – 19	Mo in excess, Cu status adequate

4.5.6 Derived Eco-SGVs

Median background concentrations of Cu determined for geological groupings with n >30, ranged from 6.7 to 25 mg/kg (Appendix A). This provides Eco-SGVs ranging from 10 mg/kg for areas of ecological significance to 290 mg/kg for commercial/industrial land use in a typical New Zealand soil (Table 31). Values for the sensitive soil and tolerant New Zealand reference soils are shown in Table 32, demonstrating the influence of soil properties, in particular CEC, on the derived Eco-SGVs. The specific background concentration to be used is dependent on the location being assessed, and can be obtained from https://lris.scinfo.org.nz/.

Table 31 Eco-SGVs for copper in a typical New Zealand soil for fresh and aged contamination, with 95th percentile background concentrations shown for comparison

Land use	Median background concentration range (mg/kg)	Eco-SGV[1]$_{(EC30fresh)}$ (mg/kg)	Eco-SGV[1]$_{(EC30aged)}$ (mg/kg)	95th percentile background concentration range (mg/kg)
Areas of ecological significance		25 – 45	45 – 65	
Non-food production land		55 – 70	100 – 120	
Agricultural land	7-25	110 – 130	220 – 240	29 – 105
Residential/recreational area		120 – 140	240 – 260	
Commercial/industrial		220 – 240	420 – 440	

[1]Values have been rounded; final Eco-SGVs should be based on background concentrations relevant to the site under assessment. Current estimates can be obtained from https://lris.scinfo.org.nz/.

Table 32 Eco-SGVs for fresh and aged copper contamination in sensitive and tolerant New Zealand reference soils

Land use	Eco-SGV[1]$_{(EC30fresh)}$ sensitive (mg/kg)	Eco-SGV[1]$_{(EC30aged)}$ sensitive (mg/kg)	Eco-SGV[1]$_{(EC30fresh)}$ tolerant (mg/kg)	Eco-SGV[1]$_{(EC30aged)}$ tolerant (mg/kg)
Areas of ecological significance	25 – 45	45 – 65	25 – 45	50 – 65
Non-food production land	45 – 65	85 – 100	65 – 85	130 – 140
Agricultural land	80 – 100	150 – 170	170 – 190	340 – 360
Residential/recreational area	95 – 110	180 – 200	170 – 190	340 – 360
Commercial/industrial	160 – 180	320 – 340	320 – 340	630 – 650

[1]Values have been rounded; final Eco-SGVs should be based on background concentrations relevant to the site under assessment. Current estimates can be obtained from https://lris.scinfo.org.nz/.

4.5.7 Comparison with international values

A summary of soil quality guidelines for copper from international jurisdictions is provided in Table 33. The derivation methodology and purpose of the SQGs shown can be different, and therefore direct comparison is problematic. However, the New Zealand Eco-SGVs for non-food production land are at the lower end of international SQGs, while the remainder of Eco-SGVs fall within the range. The Eco-SGVs in the typical and sensitive New Zealand

reference soils are similar to the Australian EILs, which are similarly derived, for different land uses in their reference soil. The Eco-SGVs for the New Zealand tolerant reference soil are higher, which is reflective of the high CEC in this soil.

Table 33 Soil quality guidelines for copper (Cu) from international jurisdictions

Jurisdiction	Name of value	Numerical value (mg/kg)		Source
New Zealand	Soil limit	100		NZWWA 2003
Australia	Ecological investigation levels[1]	Fresh	Aged	NEPC 2013a
	Areas of ecological significance	70	80	
	Urban residential/public open space	120	210	
	Commercial/industrial	170	300	
Canada	SQG-soil contact Agricultural/residential	63 (total)		Environment Canada 1999d
	SQG-soil contact commercial/industrial	91 (total)		
EU	Predicted No effect concentration – highly sensitive soil	30 (added)		Smolders et al. 2009
	moderate	93 (added)		
	Weakly sensitive soil	162 (added)		
	PNEC acid forest soil	20-170 mg/kg (total)		ECI 2008
	EU-arable sandy soil			
	EU-peat	170		
US	Eco-SSL plants	70 (total)		US EPA 2007b
	Eco-SSL invertebrates	80 (total)		
	Eco-SSL avian	28 (total)		
	Eco-SSL mammalian	49 (total)		
Denmark	Ecotoxicological soil quality criteria	30 (total)		Carlon 2007

[1]Determined by EIL calculator for Australian reference soil: pH ($CaCl_2$) = 6, clay 10%, CEC 10 cmol/kg, organic carbon 1%

4.6 Fluorine

Toxicity data were only sought for studies using an F salt, such as NaF and KF, with studies using sodium fluoracetate or alumina-F complexes excluded.

4.6.1 Toxicity data – microbes, plants and invertebrates

There are numerous studies on the phytotoxicity of F, although these are primarily concerned with the effects of aerially deposited F. In contrast, there are very few studies on the toxicity of soil F, with some of these focussed on the effects of the addition of F-containing water as opposed to the effects of soil F. As a result, only six studies on plants and two studies on microbial processes were found to be suitable for use in the derivation of Eco-SGVs (Appendix G). From these studies the toxicity of F to plants ranges from LOEC/EC30 of 100 mg /kg for *Triticum aestivum* (Singh et al. 2001) to 270 mg/kg for

Spinacia oleracea (Jha et al. 2009). For microbial activity, F is often observed to have a stimulatory effect at lower concentrations, with inhibition only occurring at higher concentrations (>5000 mg/kg; Ropewelaska et al. 2016). However, in contrast, one study suggests that F may inhibit decomposition of organic matter at soil F concentrations over 860 mg/kg and leaf litter concentrations over 73 mg/kg (Rao & Pal 1978). Similarly, Rathore and Agrawal (1989) found negative effects on plant/rhizobia interactions (as indicated by reduced nodulation) based on the addition of 10 mg/kg of NaF (4.5 mg F/kg) to soil.

One study on the toxicity of NAF on a soil invertebrate, *Eisenia fetida* was found (Dunne & Verre 2011). However, this was unable to be used as it focussed on the effects of addition of NaF-containing water (up to 4 mg/L) but did not indicate the amount of F added to the soil nor the final F concentration. No lethality or avoidance behaviour was observed at the water concentrations used. No effect of F on *Porcello scaber* was observed in leaf litter with F concentrations up to 3230 mg/kg (Van Wensem & Adema 1991). This study was also unable to be used as it does not cover the toxicity of F in soil.

Sodium fluoroacetate appears to be more toxic than F salts, with EC50 for reproduction in *Eisenia fetida* being 90 mg/kg and growth of lettuce and oats being 10 and 42 mg/kg, respectively (O'Halloran et al. 2008).

4.6.2 Livestock and wildlife

Exposure of cattle and sheep to excess F through the diet can result in damage to teeth, jaws and bones. Cronin et al. (2000) provides one of the most comprehensive discussions of the potential risks to livestock from ingestion of fluoride. Cattle are more sensitive to fluorosis than sheep, with estimated dietary tolerances of 30–50 μg/g dry matter and 60 μg/g dry matter, respectively (Cronin et al. 2000). Tolerances can be higher (>100 μg/g dry matter) if cattle or sheep are exposed to elevated F for short periods. Removal of sheep or cattle from high F input will reduce F that has accumulated over time (Grace et al. 2003, 2005). Soil ingestion is recognised as the primary route of exposure for livestock given the low concentrations in pasture (Loganathan et al. 2003, 2006; Grace et al. 2011).

Using dietary tolerances of 45 μg/g dry matter and 60 μg/g dry matter for cattle and sheep respectively, and assuming bioavailability of 75%, Cronin et al. (2000) estimated threshold F concentrations ranging from 326 to 1085 mg/kg for cattle and 372 to 1460 mg/kg for sheep based on different soil ingestion rates and soil F bioavailability (Table 34). These estimates include a contribution of F in pasture to total dietary intake. Taking the low soil ingestion rates as ingestion rates over 6 months of a drier period, and high ingestion rates as the ingestion rate for 6 months over a winter period, and taking the average of derived soil F threshold yields a provisional Eco-SGV for livestock of 450 mg/kg. This is similar to concentrations that Loganathan et al. (2006) suggested required management of the risk of fluorosis to livestock (>500 mg/kg).

Table 34 Calculated soil F concentration required to reach daily dietary intake tolerances for sheep and cattle in winter, based on dietary of tolerances of 45 and 60 μg/g dry matter, and assuming dietary bioavailability of 75% and high and low soil ingestion rates and soil bioavailability of 20% and 38% (adapted from Cronin et al. 2000)

Animal	Total matter intake (g/day)	Soil intake (g/day)	Pasture F concentration (μg/g)	Threshold soil F concentration (low) (mg/kg)	Threshold soil F concentration (high) (mg/kg)
Sheep	1000	143	5	1461	
Sheep	1000	300	5	706	
Sheep	1000	143	5		769
Sheep	1000	300	5		372
Cattle	6400	900	5	1085	
Cattle	6400	1600	5	619	
Cattle	6400	900	5		571
Cattle	6400	1600	5		326

In contrast to livestock, F in forage is considered to be the primary route of exposure for wildlife, and Pasco et al. (2014) developed risk-based soil concentrations for a range of terrestrial wildlife. The lowest soil NOAEL and LOAEL RBCs were 149 mg/kg (coyote) and 659 mg/kg (deer mouse). The LANL ECORISK database (2012, in Pasco et al. 2014) provided ranges of NOAEL-based soil ecological screening levels (ESLs) for birds ranging from 54–1000 mg/kg and for mammals ranging from 120–4600 mg/kg – illustrating the influence of diet on derived risk-based soil concentrations. Thus, more information on the diet of New Zealand wildlife is required to enable the development of risk-based soil concentrations to protect New Zealand wildlife. An indicative estimate may be obtained from the soil RBCs for the horned lark, which has a diet of 80% forage and 20% insects, and thus is similar to New Zealand birds. For this bird, soil RBCs based on NOAEL of 456 mg/kg based on no observed effects, with RBCs based on LOAEL levels being >1000 mg/kg.

4.6.3 Derived ACLs

There are data for five plant species and two microbial processes (Appendix G), which is just sufficient to use the SSD approach. The sensitivities of the different organisms were overlapping (Figure 8), hence all data were used to derive ACLs. The derived ACLs have very wide confidence limits given the limited amount of data (Table 35), thus they are considered to be of low reliability. There were insufficient data to separate plant toxicity data from invertebrate and microbial process data so the ACL for agricultural land use is based on 95% protection for all species, and thus is the same as non-production land.

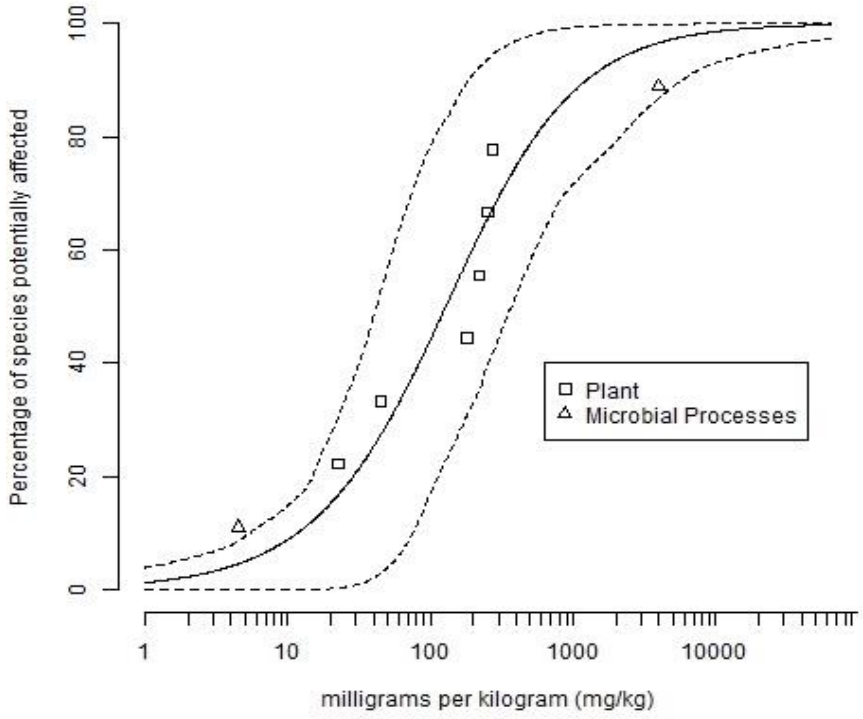

Figure 8 The SSD of 30% effect concentration (EC30) toxicity data for fluoride contamination for terrestrial plants, invertebrates and soil microbial processes.

Table 35 Added concentration limits (ACL) derived for fluoride using LOEC/EC30 toxicological endpoints

Land use	ACL $_{(EC30)}$ (mg/kg)	ACL $_{(EC30)}$ (mg/kg) 95% CI
Areas of ecological significance	0.5	0.1 – 71
Non-food production land	5	1.7 – 111
Agricultural land (Plants)	5	1.7 – 111
Residential/recreational	29	7 – 186
Commercial/industrial	83	32 – 231

4.6.4 Derived Eco-SGVs

Kim et al. (2016) provide some of the only published data on background soil F concentrations in different soil types in New Zealand. These authors found background concentrations of F in soils collected from Waikato and Bay of Plenty regions varied from 16 mg/kg to 265 mg/kg in soils derived from different parent materials. Grouping these into volcanic soils and sandstone/siltstone/greywacke yields the Eco-SGVs shown in Table 37.

Table 36 Added contaminant limits (ACL), background concentrations and Eco-SGVs for fresh and aged copper contamination in sensitive and tolerant New Zealand reference soils

Land use	Soil	Background F concentration (mg/kg)	ACL (mg/kg)	Eco-SGV[1] (mg/kg)
Areas of ecological significance	Volcanic soils	122 – 265	0.5	120 – 260
	Sandstone, siltstone, greywacke	204		200
Agricultural land and non-food production land	Volcanic soils	122 – 265	5	130 – 270
	Sandstone, siltstone, greywacke	204		210
Residential/recreational	Volcanic soils	122 – 265	29	150 – 290
	Sandstone, siltstone, greywacke	204		230
Commercial/industrial	Volcanic soils	122 – 265	83	200 – 350
	Sandstone, siltstone, greywacke	204		290

[1]Values have been rounded; final Eco-SGVs should be based on background concentrations relevant to the site under assessment.

The ACLs for areas of ecological significance, agricultural land and non-production land are small in comparison to measured background F concentrations, making it difficult to identify when a negative effect is actually occurring. Further, there are overlapping effects arising from added F depending on what species are being examined. Notably, F addition appears to largely stimulate microbial processes at lower concentrations, with negative effects at higher concentrations potentially attributed to pH changes rather than F toxicity. However, the available literature also suggests that negative effects of F on soil rhizobia and plants may occur at lower concentrations, and lower than that which may lead to fluorosis (>450 mg/kg). Further research is required to provide additional data to enable more robust soil guideline values to be developed; thus, the derived Eco-SGVs are considered provisional and are not recommended for use.

4.6.5 Comparison with international values

No internationally developed SQGs for F were found to compare with the provisional Eco-SGVs.

4.7 Lead

4.7.1 Data compilation and screening

Data on chronic single-species toxicity tests for plants, invertebrates and microbial studies are summarised in Appendix H. To maximise the use of existing data, conversion factors (Table 5) were used to convert data into different endpoints. For plants, aged LOEC/EC30 in seven species of plants ranged from 205 mg/kg for *Lactuca sativa* to 26 000 mg/kg for *Triticum aestivum* (Appendix H). Plant toxicity data included only agricultural species, so all plant data were used to derive the ACL for agricultural plant species. In 11 species of invertebrates aged LOEC/EC30s in different soils ranged from 35 mg/kg for reproduction

in *Folsomia candida* to 13 000 mg/kg for *Folsomia candida* in a different soil. Tests on microbial processes are multi-species tests in which the native soil microbial community is exposed. The selected LOEC /EC30 values comprise functional parameters including enzymatic activities (n = 64). The functional parameters are based on the carbon cycle (n = 26); nitrogen cycle (n = 24), including denitrification and mineralisation of specific substrates; phosphorus cycle (n = 7); and sulphur cycle (n = 8).

Toxicity data were typically presented in terms of added concentration and so were used without further modification. There are numerous studies on the transfer of Pb through the food chain and a recent EU ecological risk assessment of lead derived a predicted no effect oral dietary intake of 49 mg/kg_{ww} as a basis for assessing the risk of secondary poisoning. That value was derived by statistical extrapolation from $NOEC_{oral}$ values of laboratory feeding studies, with the risk of secondary poisoning considered to be most critical for the terrestrial environment. This was used, along with a median soil-earthworm bioaccumulation factor value (0.1), to predict a risk to mammals and earthworm-eating birds above soil Pb concentrations of 491 mg/kg. This estimate was lower than the soil concentration predicted to have no effect on microbes, plants and invertebrates (300 mg/kg). Thus Pb is not considered to pose a biomagnification risk through the food chain and the protection level for non-biomagnifying contaminants was used to generate the ACL for each land use.

4.7.2 Ageing

Lead Development Association International (LDAI 2008) evaluated toxicity in soils specifically set up to examine the influence of ageing on Pb toxicity. This study found that limited toxicity occurred in the aged soils, sometimes with no toxicity observed at the highest dose. This gives rise to unbounded estimates of ageing-leaching factors ranging from 1.1 to 43, with a median value of 4.2. The only bounded factor that could be determined was also 4.2, and LDAI (2008) selected this value on the basis it was a measured factor, but also corresponded to the estimates based on all data. This is also reported in Smolders et al. (2009), and an ageing/leaching factor of 4.2 is used in NEPC (2013b) to derive EILs for Pb. Smolders et al. (2015) found limited toxicity in soils aged (5 yrs), leached soils, while Lock et al. (2006) observed no toxicity (at >5460 mg/kg) to *Folsomia candida* in three aged soils. In this latter study, spiked, and spiked and leached soils were toxic in the concentration range of 2060–3210 mg/kg.

An ALF was calculated in this study using only bounded EC10 data based on added Pb concentrations provided in Smolders et al. (2015) and Waegeneers et al. (2004, in LDAI 2008). This also was 4.2, hence this ALF was used in this study.

4.7.3 Normalisation

A number of studies have examined the influence of soil properties on Pb toxicity. Nan et al. (2002) found that Pb uptake by spring wheat (*Triticum aestivum*) depended on Pb and Zn concentrations. Hamon et al. (2003, in NEPC 2013a) found that clay content was the most significant influence of Pb toxicity to lettuce (*Lactuca sativa*). Bradham et al. (2006) found that organic carbon, iron and aluminium oxides and CEC influenced the toxicity of Pb to earthworms. Similarly, Dayton et al. (2006) found organic carbon, iron and

aluminium oxides and CEC influenced the toxicity of Pb to lettuce, while Luo et al. (2014b) related the effects of Pb on survival and reproduction in *Enchytraeus crypticus* to soil properties and total, water- and $CaCl_2$ -extractable and porewater Pb concentrations. The Australian National Environment Protection Council (NEPC 2013a) also examined the relationship between Pb toxicity and soil properties and found that the logarithm of Pb toxicity to plants and the logarithm of the organic carbon content was able to explain more than 50% of the variation in toxicity data (r^2 = 0.56), although the majority of the relationships derived explained less than 10% of the variation in toxicity data. Lead Development Association International (LDAI 2008) found no relationship between soil pH and Pb toxicity. Normalisation relationships could not be used to develop ACLs as all studies were limited by one of more of the following: the number of soils used to develop the relationship were limited, the variation explained by the relationship was insufficient, there was a lack of validation of the relationship, relationships were developed using variables typically not measured in toxicity studies (iron and aluminium oxides in particular).

4.7.4 Derived ACLs

There were 123 selected toxicity measures from 8 plant species, 11 invertebrate species and 13 microbial processes, including 6 enzymatic processes, meeting the minimum requirements for the use of SSD to derive ACLs. The sensitivities of the different organisms were overlapping (Figure 9), hence all data were used to derive ACLs.

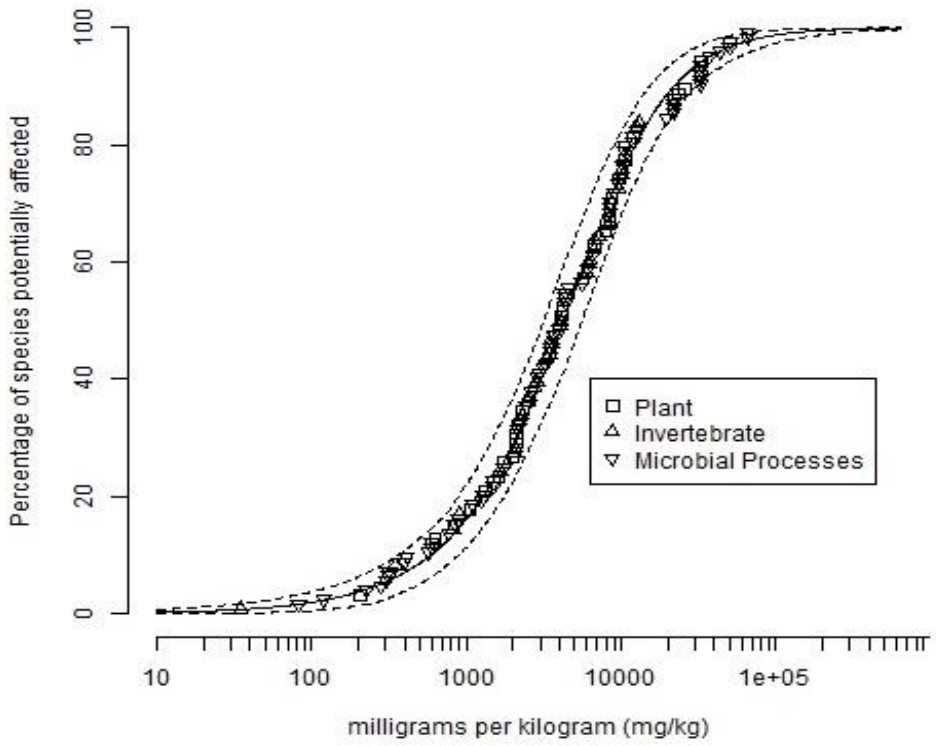

Figure 9 The SSD of 30% effect concentration (EC30) toxicity data for aged lead contamination for terrestrial plants, invertebrates and soil microbial processes.

As toxicity data were not able to be normalised to the New Zealand reference soils, a generic ACL for each land use was derived (Table 37) and applies to all New Zealand soils of the appropriate land use. For agricultural land, the ACL derived for protection of 95% of plant species is lower than that for protection of 80% of soil processes and invertebrates, thus the agricultural value is based on protection of plant species. Given the high Pb concentrations for ACLs derived for agricultural land, residential and commercial landuse, and wide confidence intervals of estimates, ACLs to provide protection from secondary poisoning were also derived. It should be noted there is a wide spread in the estimates

No studies reported toxicity occurring below the most protective ACL (49 mg/kg), although some effects on microbial activity were reported to occur at slightly higher concentrations, and below ACLs for non-food production land, agricultural land, and residential/recreational land use. This is largely indicative of the lower protection level afforded by these ACLs (particularly residential).

Table 37 Added concentration limits (ACL) derived for lead using NOEC/EC10 and LOEC/EC30 toxicological endpoints for aged contamination

Land use	ACL (EC10) (mg/kg)	ACL (EC10) (mg/kg) (95% CI)	ACL (EC30) (mg/kg)	ACL (EC30) (mg/kg) (95% CI)	ACL (EC30BM)
Areas of ecological significance	26	7.5 – 165	49	16 – 180	-
Non-food production land	159	81 – 312	275	149 – 514	-
Agricultural land (Plants)			522	185 – 1546	160
Agricultural land (Soil process and invertebrates)			1209	836 – 1757	-
Residential/recreational	796	557 – 1102	1276	904 – 1760	918
Commercial/industrial	1966	1461 – 2617	3049	2283 – 4406	2541

4.7.5 Derivation of Eco-SGVs

Median background concentrations of Pb determined for geological groupings with n >30, (Appendix A) ranged from 6.8 to 16.5 mg/kg. This provides Eco-SGVs ranging from 55 mg/kg for areas of ecological significance to 3000 mg/kg for commercial/industrial land use or 2500 mg/kg when biomagnification is taken into account (Table 38). The specific background concentration to be used depends on the location being assessed, and can be obtained from https://lris.scinfo.org.nz/. The ranges of estimated 95th percentile concentrations are also shown in Table 38 for comparison. With the exception of areas of ecological significance, the background concentration of Pb makes a negligible contribution to the derived Eco-SGVs. Given the high concentrations for residential and commercial land use, and noting a preliminary PNEC derived by the EU ecological risk assessment of 490 mg/kg soil, it is recommended that a higher protection level is used for these land uses (where large areas are under assessment) to provide protection against secondary poisoning.

Table 38 Eco-SGVs for lead, with median and 95th percentile background concentrations shown for comparison

Land use	Median background concentration range (mg/kg)	Eco-SGV1 (EC30) (mg/kg)	Eco-SGV1 (EC30) BM2 (mg/kg)	95th percentile background concentration range (mg/kg)
Areas of ecological significance	7 – 15	55 – 65	NA	25 – 55
Non-food production land		280 – 290	NA	
Agricultural land		530 – 540	NA	
Residential/recreational		1300	900	
Commercial/industrial		3000	2500	

[1]Values have been rounded; final Eco-SGVs should be based on background concentrations relevant to the site under assessment. Current estimates can be obtained from https://lris.scinfo.org.nz/.

[2]BM-biomagnification, recommended for use to account for secondary poisoning at high concentrations of Pb.

4.7.6 Comparison with other guideline values

A summary of soil quality guidelines for Pb from international jurisdictions is provided in Table 39. The derivation methodology and purpose of the SQGs shown can be different, and therefore direct comparison is problematic. The New Zealand Eco-SGVs for all land uses except ecologically sensitive areas are higher than most international SQGs. The Eco-SGVs are slightly lower than the aged Australian EILs, which are similarly derived, for different land uses. The Eco-SGV for agricultural land is markedly higher than the Canadian SQG for agriculture, which is based on soil and food ingestion by wildlife and livestock and is based on a food web approach. The Eco-$SGV_{agriculture}$ is more similar to the Canadian SQG for residential land use based on soil contact, which is similarly derived although is based on different underlying data.

Table 39 Soil quality guidelines for lead (Pb) from international jurisdictions

Jurisdiction	Name of value	Numerical value (mg/kg)		Source
New Zealand	Soil limit	300		NZWWA 2003
Australia	EILs	Fresh	Aged	NEPC 2013b
	Areas of ecological significance	110	470	
	Urban residential/public open space	270	1100	
	Commercial/industrial	440	1800	
Canada	SQG-soil food ingestion Agricultural	70		Environment Canada 1999e
	SQG-soil contact residential	300		
	SQG-soil contact commercial/industrial	600		
EU	PNEC	86 (total, background = 15 mg/kg)		LDAI 2008
	PNEC	166 (added)		Smolders et al. 2009
	Preliminary PNEC - wildlife	491		LDAI 2008
US	Eco-SSL plants	120		US EPA 2005c
	Eco-SSL invertebrates	1700		
	Eco-SSL avian	11		
	Eco-SSL mammalian	56		
Denmark	ecotoxicological soil quality criteria	50		Carlon 2007

4.8 Zinc

4.8.1 Data compilation and screening

Data on chronic single-species toxicity tests for plants, invertebrates and microbial studies are summarised in Appendix I. To maximise the use of existing data, conversion factors (Table 5) were used to convert data into different endpoints. For plants, aged LOEC/EC30 in 17 species of plants ranged from 250 mg/kg for *Sorghum bicolour* to 12 500 mg/kg in *Agrostis tenuis* (Appendix I). There was one non-agricultural plant species, thus toxicity data were available for 10 plant species for the development of ACLs for agricultural land use. In 10 species of invertebrates aged LOEC/EC30s in different soils ranged from 250 mg/kg for cocoon production in *Eisenia andrei* to 2500 mg/kg for reproduction in the remaining species (Appendix I). Tests on microbial processes are multi-species tests, in which the native soil microbial community is exposed. The selected LOEC/EC30 values comprise 17 microbial processes, including eight enzymatic processes (n = 42), and range from 100 mg/kg for respiration to 3250 mg/kg for phosphatase activity in different soils. The functional parameters are based on the carbon cycle (n = 41), nitrogen cycle (n = 39), phosphorus cycle (n = 13) and sulphur cycle (n = 9).

Toxicity data were typically presented in terms of added concentration and so were used without further modification. Zinc does not biomagnify, so the protection level for non-biomagnifying contaminants was used to generate the ACL for each land use.

4.8.2 Ageing and leaching

Smolders et al. (2009) evaluated existing literature to assess the effects of ageing and leaching on the toxicity of Zn. These authors found that toxicity was typically reduced after leaching and ageing with a median ALF of 3 derived for Zn. This ALF was also discussed and used in the EU Risk Assessment report (EC 2008).

4.8.3 Normalisation

The Australian National Environmental Protection Council (NEPC 2013b) identified seven normalisation relationships reported in the literature for Zn, including relationships developed in European and Australian soils. Soil pH and CEC were the key variables influencing toxicity. Anderson and Basta (2009) similarly found that CEC but also organic carbon were the key soil properties influencing toxicity. The relationships developed by Anderson and Basta (2009) were not used as they were based on a small number of soils and were not validated. The relationships used to normalise the toxicity data are shown in Table 40. As with copper, appropriate Australian normalisation relationships were applied to Australian toxicity data European normalisation relationships to European toxicity data. The relationship derived by Smolders et al. (2003, in NEPC 2013b) for potential nitrification rate (PNR) was used to adjust toxicity to microbes in European soils while the relationship derived by Broos et al. (2007) for SIN was used to adjust toxicity for microbial processes in Australian soils. The relationship for *Eisenia fetida* were applied to all soft-bodied invertebrates, and that for *Folsomia candida* applied to all hard-bodied invertebrates. The normalisation relationship developed by Warne et al. (2008b) for wheat was used for Australian wheat toxicity data, while that developed by Smolders et al. (2003) was applied to the remainder of the data. The relationships developed for invertebrates and plants in European soils were used to normalise toxicity data in the EU ecological risk assessment of Zn (EC 2008).

Table 40 Normalisation relationships for the toxicity of zinc to soil invertebrates, soil processes and plants (NEPC 2013)

Species/soil process	Y parameter	X parameter(s)	Reference
European relationships			
E. fetida (earthworm)	log EC_{50}	0.79 * log CEC	Lock & Janssen 2001b
F. candida (collembolan)	log EC_{50}	1.14 * log CEC	Lock & Janssen 2001b
PNR	log EC_{50}	0.15 * pH	Smolders et al. (2003, in NEPC 2013b)
T. aestivum (wheat)	log EC_{50}	0.12 * pH +0.89 * log CEC + 1.1	Smolders et al. 2003
Australian relationships			
SIN	log EC_{50}	0.34 * pH + 0.93	Broos et al. 2007
T. aestivum (wheat)	log EC_{10}	0.271 * pH +0.702 * CEC + 0.477	Warne et al. 2008b

CEC = cation exchange capacity ($cmol_c/kg$); OC = organic carbon content (%); PNR = potential nitrification rate; SIN = substrate induced respiration.

4.8.4 Derived limits

There were 242 selected toxicity measures from 17 species of plants, 10 invertebrate species and 17 microbial processes, including 8 enzymatic processes, meeting the minimum requirements for the use of SSD to derive ACLs. As data were normalised to the New Zealand reference soils, the geometric mean was calculated for each plant and invertebrate species and microbial process for use in the SSD. The sensitivities of the different organisms were overlapping (Figure 10), hence all data were used to derive ACLs. Zinc present in urban stormwater that may be discharged to land is in a similar form to Zn solutions used to spike soils for toxicity testing. Added Contaminant Limits were derived for fresh and aged contamination for each of the three New Zealand reference soils (Tables 41 & 42). For agricultural land, the ACL derived for protection of 95% of plant species is lower than for than protection of 80% of invertebrate species and microbial processes, thus the Eco-SGV for agricultural land was based on protection of plant species.

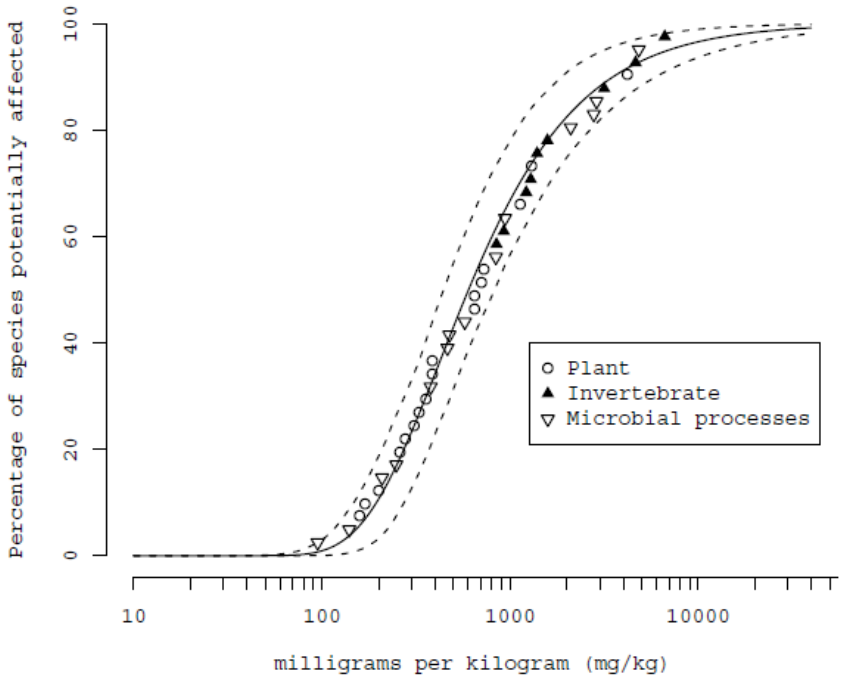

Figure 10 The SSD of 30% effect concentration (EC30) toxicity data for aged zinc contamination for terrestrial plants, invertebrates and soil microbial processes.

Table 41 Added concentration limits (ACL) derived for Zn using NOEC/EC10 and LOEC/EC30 toxicological endpoints for fresh and aged contamination for the typical New Zealand reference soil

Land use	ACL $_{(EC10fresh)}$ fresh (mg/kg)	ACL $_{(EC10aged)}$ (mg/kg)	ACL $_{(EC30fresh)}$ (mg/kg)	ACL $_{(EC30aged)}$ (mg/kg)
Areas of ecological significance	25	68	30	102
Non-food production land	37	100	55	152
Agricultural land (Plants)	46	110	70	166
Agricultural land (Soil processes and invertebrates)	52	140	79	407
Urban residential/public open space	68	177	110	273
Commercial/industrial	116	295	187	463

Table 42 Added concentration limits (ACL) derived for Zn using LOEC/EC30 toxicological endpoints for fresh and aged contamination for the sensitive and tolerant New Zealand reference soils

Land use	ACL $_{(EC30fresh)}$ sensitive (mg/kg)	ACL $_{(EC30aged)}$ sensitive (mg/kg)	ACL $_{(EC30fresh)}$ tolerant (mg/kg)	ACL $_{(EC30aged)}$ tolerant (mg/kg)
Areas of ecological significance	34	87	44	133
Non-food production land	50	131	72	203
Agricultural land (Plants)	49	109	94	240
Urban residential/public open space	62	236	133	361
Commercial/industrial	84	404	223	597

4.8.5 Derived Eco-SGVs

Median background concentrations of Zn determined for geological groupings with n >30, ranged from 24 to 44 mg/kg (Appendix A). This provides Eco-SGVs ranging from 30 mg/kg for areas of ecological significance to 500 mg/kg for commercial/industrial land in a typical New Zealand soil (Table 43). Values for a sensitive soil and tolerant soil are shown in Table 44. The specific background concentrations used is dependent on the location being assessed, and can be obtained from https://lris.scinfo.org.nz/.

Table 43 Eco-SGVs for fresh and aged zinc contamination in the typical New Zealand reference soil, with 95th percentile background concentrations shown for comparison

Land use	Eco-SGV[1] (EC30fresh) (mg/kg)	Eco-SGV[1] (EC30aged) (mg/kg)	95th background concentration range (mg/kg)
Areas of ecological significance	55 – 75	120 – 140	
Non-food production land	80 – 100	170 – 190	
Agricultural land	95 – 110	190 – 210	100 – 180
Urban residential/recreational area	130 – 150	300 – 320	
Commercial/industrial	211 – 230	480 – 500	

[1]Values have been rounded; final Eco-SGVs should be based on background concentrations relevant to the site under assessment.

Table 44 Eco-SGVs for fresh and aged zinc contamination in the sensitive and tolerant New Zealand reference soils

Land use	Eco-SGV(EC30) Sensitive soil		Eco-SGV(EC30) Tolerant soil	
	fresh (mg/kg)	aged (mg/kg)	fresh (mg/kg)	aged (mg/kg)
Areas of ecological significance	60 – 80	110 – 130	70 – 90	160 – 180
Non-food production land	75 – 95	150 – 170	95 – 120	230 – 250
Agricultural land (Plants)	75 – 95	130 – 150	120 – 140	265 – 280
Urban residential/public open space	90 – 105	260 – 280	160 – 180	380 – 400
Commercial/industrial	110 – 130	430 – 450	250 – 270	620 – 640

[1]Values have been rounded; final Eco-SGVs should be based on background concentrations relevant to the site under assessment.

4.8.6 Comparison with other guideline values

A summary of SQGs for Zn from various jurisdictions is provided in Table 45. The derivation methodology and purpose of the SQGs shown can be different, and therefore direct comparison with the Eco-SGVs and each other is problematic. The guidelines for Zn range from 20 mg/kg (added Zn) for the Netherlands to 200 mg/kg (total Zn) for Canada. The New Zealand Eco-SGVs for all land uses except ecologically sensitive areas are higher than most international SQGs. The Eco-SGVs are slightly lower than the Australian EILs, which are similarly derived, for different land uses.

Table 45 Soil quality guidelines for zinc (Zn) from international jurisdictions (adapted from NEPC 2013)

Jurisdiction	Name of value	Numerical value (mg/kg)		Source
New Zealand	Soil limit	300		NZWWA 2003
Australia	$ACL_{(LOEC \& EC30)}$	Fresh[1]	Aged[1]	NEPC 2013b
	Areas of ecological significance	40 (ACL)	90 (ACL)	
	Urban residential/public open space	160 (ACL)	400 (ACL)	
	Commercial/industrial	250 (ECL)	630 (ACL)	
Canada	SQG-soil contact Agricultural/residential	200		Environment Canada 1999f
	SQG-soil contact commercial/industrial	360		
EU	Predicted No effect concentration – highly sensitive soil[2]	24 (added)		Smolders et al. 2009
	Moderate sensitive soil[2]	94 (added)		
	Weakly sensitive soil[2]	246 (added)		
	PNEC in a range of soils	20-170 mg/kg (total)		EC2008
US	Eco-SSL plants	160		US EPA 2007c
	Eco-SSL invertebrates	120		
	Eco-SSL avian	46		
	Eco-SSL mammalian	79		
Denmark	Ecotoxicological soil quality criteria	100		Carlon 2007

[1]based on the Australian reference soil (ph = 6, CEC = 10cmol/kg)

Highly sensitive soil pH = 4.5, CEC = 4 cmol.kg, clay = 5, %OC = 1; moderately sensitive soil pH = 5.5, CEC 15 cmol.kg, % clay = 15, % OC = 2.9 ; weakly sensitive soil pH = 7, CEC = 35 cml/kg, % clay = 30; % OC = 12.

4.9 DDT

DDT (dichlorodiphenyltrichloroethane) was a widely used organochlorine pesticide in New Zealand (Buckland et al 1998). The active ingredient and the main constituent of technical DDT is p,p′-DDT (approx 87% of DDT). Other compounds present include o,p′-DDT (15% of DDT), dichlorodiphenyldichloroethylene (DDE) and dichlorodiphenyldichloroethane (DDD). The latter two are also metabolites and breakdown products of DDT. DDE is the dominant compound typically present in soils to which DDT has historically been applied.

4.9.1 Toxicity data

Data on chronic single-species toxicity tests for plants, invertebrates and microbial studies are summarised in Appendix J. To maximise the use of existing data, conversion factors (Table 5) were used to convert data into different endpoints. There are limited data on the toxicity of DDT to different organisms. A recent study found DDT had a very low toxicity (i.e. EC50 > 1000 mg/kg) to microbial processes, two plant species and two invertebrate species in three soil types (Hund-Rinke & Simon 2005). However, most of the data

generated were unbounded, that is toxicity (EC50) was greater than the highest tested concentration, and no indication was given as to whether any effects were observed at the lower concentrations. Only bounded data (2 data points) provided by this study was used. It was noted that the toxicity of DDT in this study was markedly lower than that observed in many earlier studies; the reason for this is unclear although it is noted that Hunde-Rinke and Simon (2005) aged their soils for 14 days prior to toxicity testing and some earlier studies report using technical grade DDT, which may include additional compounds that contribute to the observed toxicity. Given the paucity of toxicity data on DDT, older studies provided in Environment Canada (1999g) were also used, despite not sighting the original references. This was considered appropriate as these studies had been previously screened and used for guideline derivation by the Canadians. For plants, LOEC/EC30 in 16 species of plants ranged from 12 mg/kg for black valentine beans to 1200 mg/kg for *Lolium perenne,* with soil algae being the most sensitive with an LOEC/EC30 of 7.3 mg/kg (Appendix J). In six species of invertebrates, LOEC/EC30 ranged from 2.5 mg/kg in unspecified earthworm species to 166 mg/kg in *Folsomia candida*. There were three microbial processes covering the nitrogen cycle, with LOEC/EC30 ranging from 12.5 mg/kg to over 3000 mg/kg.

DDE is the main degradation product of DDT in soils; however, despite the vast literature on the accumulation of DDE into plants and animals – particularly birds – there are very limited data on the toxicity of DDE to microbes, plants or soil invertebrates. Chung et al. (2007) provide some data on the toxicity of DDE to plants and microalgae. These authors found that DDE was more toxic to root growth of *Lolium perenne* than DDT, with EC10s of 114 mg/kg and 483 mg/kg, respectively. Similarly, DDE was more toxic to soil algae than DDT, with EC10s of 1.14 mg/kg and 2.9 mg/kg, respectively. Given the limited data for DDE, Eco-SGVs were only developed for DDT. As DDT is known to biomagnify, Eco-SGVs accounting for biomagnification were determined.

4.9.2 Ageing and normalisation

It is well known that the organic carbon or organic matter content of soils affects the toxicity and bioavailability of organic contaminants such as DDT. However, there were no normalisation relationships available for DDT, and infrequently information on the organic carbon content of the tested soils. Therefore, the toxicity data could not be normalised to the New Zealand reference soils. Similarly, there are no studies that have assessed the influence of ageing on DDT toxicity.

4.9.3 Derived limits

There were 26 selected toxicity measures from 16 species of plants, six invertebrate species and three microbial processes meeting the minimum requirements for the use of SSD to derive ACLs. The sensitivities of the different organisms were overlapping (Figure 10), hence all data were used to derive ACLs.

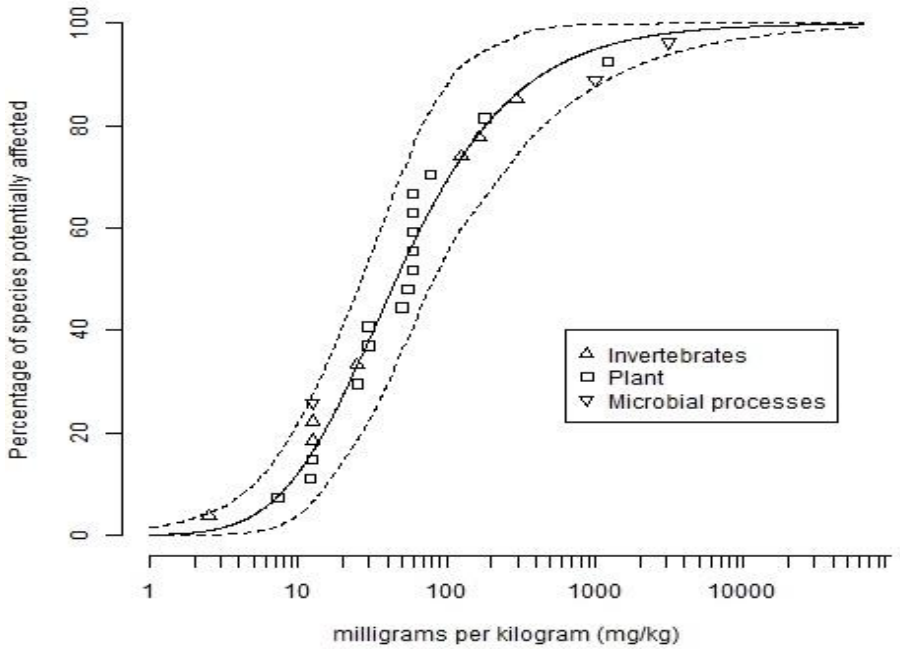

Figure 11 The SSD of 30% effect concentration (EC30) toxicity data for DDT contamination for terrestrial plants, invertebrates and soil microbial processes.

As toxicity data were not able to be normalised to the New Zealand reference soils, a generic ACL for each land use was derived (Table 46) and applies to all New Zealand soils of the appropriate land use. For agricultural land, the ACL derived for protection of 95% of plant species is lower than that for protection of 80% of soil processes and invertebrates, thus the agricultural value is based on protection of plant species. The limited amount of data gives rise to wide confidence intervals for the estimated ACLs, and the ACLs are considered to be of moderate reliability.

Thompson 1971 (in Environment Canada 1999g) reported reduction in earthworm biomass occurring below the most protective ACL (1.1 mg/kg). Some studies reported toxicity to plants and invertebrates occurring at concentrations in the same range as the ACLs for non-food production land, agricultural land, and residential/recreational land use (Appendix J). This is largely indicative of the lower protection level afforded by these ACLs (particularly residential).

Table 46 Added concentration limits (ACLs) developed for DDT based on NOEC/EC10 and LOEC/EC30 toxicity endpoints

Land use	Eco-SGV $_{(EC10)}$ (mg/kg)	Eco-SGV $_{(EC10)}$ (mg/kg) (95% CI)	Eco-SGV$_{(EC30)}$ (mg/kg)	Eco-SGV $_{(EC30)}$ (mg/kg) (95% CI)
Areas of ecological significance	1.1	(0.34 – 3.5)	2.6	0.81 – 8.2
Non-food production land	2.4	(1.2 – 5.6)	5.7	2.9 – 13
Agricultural land (Plants)	3.8	2.1 – 10	9.9	5.3 – 23
Agricultural land (Plants) -biomagnification	1.9			
Agricultural land (Soil process and invertebrates)	4.6	1.8 – 30	10	4.2 – 44
Residential/recreational area	6.2	3.5 – 11	15	8.4 – 27
Residential/recreational area - 85% protection Level	4.8	2.8 – 9	12	6.7 – 23.4
Commercial/industrial	14	8.5 – 23	32	20 – 60
Commercial/industrial – 65% protection Level	11	6.8 – 19	27	16 – 53

4.9.4 Derivation of Eco-SGVs

As DDT is a xenobiotic, it is not considered to have a background concentration (see also Cavanagh et al. 2016); thus the ACLs generated above effectively become the Eco-SGVs. Despite the expectation that there is a low risk of biomagnification in New Zealand food webs, Cavanagh et al. (2015) found high concentrations of DDTs, predominantly *p,p*-DDE, in Australasian harriers from the Canterbury region. This was unexpected as residues in the surrounding agricultural soils were not anticipated to be high. The high concentrations in the harriers were attributed to a potentially high proportion of birds (which have limited metabolism of DDT and DDE) in the harriers' diet, although this requires verification. However, as discussed earlier, given the diet of many common birds in urban/rural areas that harriers may feed on, biomagnification is anticipated to be low. Low concentration of DDTs found in the body fat of mallards supports this expectation (Cavanagh et al. 2015). Regardless, given the observation of apparent marked biomagnification up the food chain in a region with low DDT soil concentrations, it is recommended that a more conservative Eco-SGV is set for DDT. Specifically, it is recommended that the Eco-SGV be based on the NOEC/EC10 data, including the biomagnification pathway (Table 47). Further research is required to develop robust Eco-SGVs for DDT and its degradation products.

Table 47 Added concentration limits (ACLs) developed for DDT based on NOEC/EC10 and LOEC/EC30 toxicity endpoints

Land use	Eco-SGV $_{(EC10)}$ (mg/kg)
Areas of ecological significance	1.1
Non-food production land	2.4
Agricultural land (Plants)	1.9
Residential/recreational area – 85% Protection level	4.8
Commercial/industrial – 65% Protection level	11

4.9.5 Comparison with other guideline values

A compilation of SQGs for DDT from a number of jurisdictions is presented in Table 48. The derived Eco-SGVs are lower than the EILs derived for DDT for the equivalent land use in Australia, despite the similarity in methods. This difference arises largely from the selection of different toxicity data. For example, toxicity data for terrestrial vertebrates were excluded from the Eco-SGV data compilation. The latter was excluded as it could not be verified that DDT contaminated soil was the source of exposure in the toxicity studies; intake based on diet will be variable and dependent on DDT soil concentrations. The Eco-SGVs for non-food production land and agricultural land were higher than the Canadian Agriculture SQG based on soil and food ingestion, and lower than the Canadian SQG for soil contact for agricultural and residential land use. The US Eco-SSL for DDT for the protection of birds and mammals is much lower than the derived Eco-SGVs. Given the observation of apparent significant biomagnification of DDTs in Australasian harriers, it is appropriate to set low Eco-SGVs for DDT.

Table 48 Soil quality guidelines for *p,p*-DDT from international jurisdictions

Jurisdiction	Name of value	Numerical value (mg/kg)	Source
Australia	$SQG_{(LOEC\ \&\ EC30)}$ Fresh		NEPC 2013a
	Areas of ecological significance	3	
	Urban residential / public open space	180	
	Commercial/industrial	640	
Canada	SQG-soil & food ingestion Agricultural / residential	0.7	Environment Canada 1999g
	SQG-soil contact Commercial/industrial	12	
US	Eco-SSL plants	NA	US EPA 2007d
	Eco-SSL invertebrates	NA	
	Eco-SSL avian	0.093	
	Eco-SSL mammalian	0.021	

4.10 Total petroleum hydrocarbons

Total petroleum hydrocarbons (TPH) is a term used to describe a wide range of compounds that originally come from crude oil. These compounds may be aliphatic or aromatic, with composition, and thus toxicity, of different crude oils and different products being variable.

4.10.1 Toxicity data

There are limited data on the toxicity of TPH to ecological receptors with research commissioned by the Canadian Council of Ministers for the Environment being the only systematic effort to generate data suitable to develop soil guideline values for TPH. These data are captured in *Canada-Wide Standard for Petroleum Hydrocarbons (PHC) in Soil: Scientific Rationale* (CCME 2008a), which provides the most recent comprehensive evaluation of the toxicity of petroleum hydrocarbons, and specifically TPH, in the soil environment. The Canadian data are based on a fractionation scheme (F1: C6–C10, F2: >C10–C16, F3: >C16–C34 and F4: >C34) that differs slightly to that used in New Zealand (F1:C7–C9, F2:>C9–C15, F3:>C15–C36), although the data generated are considered generally applicable to New Zealand for the current purpose.

Data for the toxicity of F1 were generated for four plant species and two invertebrate species with EC25 ranging from 190 mg/kg for alfalfa growth to 510 mg/kg for survival of *Eisenia andrei*. Toxicity of F2 to three plant species and two invertebrate species ranged from 79 mg/kg for northern wheatgrass to 284 mg/kg for barley growth. Data were sufficient to use the SSD approach to derive values.

Toxicity data for F3 were available from a number of studies and CCME (2008a) placed the greatest emphasis on a field study that considered 14 species and assessed crop growth and invertebrate populations in a field setting. Toxicity values in a fine soil ranged from an EC20 of 510 mg/kg for reproduction in *Onychiurus folsomia* to 49 000 mg/kg for barley growth. Toxicity in a coarse soil was >10 000 mg/kg.

Toxicity data for F4 was based on studies of the toxicity of whole crude oil, with EC20 2240 mg/kg for northern wheatgrass root mass to 5300 mg/kg in barley (CCME 2008a). EC20s were unable to be calculated for soil invertebrates and EC50 was >4000 mg/kg (CCME 2008a).

4.10.2 Normalisation and ageing

Toxicity data for TPH could potentially be normalised on the basis of organic carbon content, since organic compounds are known to bind to organic matter. However, there is no information on organic carbon content in the original test soils. There are also no data able to include the effects of ageing. While it is generally expected that ageing may reduce the toxicity of TPH, the generation of more toxic degradation products can result in aged contamination being more toxic.

4.10.3 Derived limits

Warne (2010a) provides a review of the Canadian soil quality guidelines for TPH for use in Australia. He noted the data reduction method used by the Canadians differs from that used by others to calculate guidelines values using SSD approaches. Specifically, multiple endpoints for a given species were used. As such, Warne (2010a) recalculated SQG for F1 and F2 using the lowest endpoint for a given species from the Canadian data and using BurrliOZ. However, as Warne (2010a) did not calculate protection levels that are relevant for all the New Zealand land use categories, these same data were used to calculate Eco-SGVs also using BurrliOZ in this study. Despite using the same data, different SQGs to Warne (2010a) were obtained using the same protection levels (Table 49). It is unclear why this is the case, although it is noted that the current version of BurrliOZ does not allow for selection of the curve used to fit the SSD but rather this is automatically selected based on the amount of data available. To ensure consistency with Eco-SGVs derived for other contaminants, the SQGs developed in this study for F1 and F2 are recommended for use. Agriculture and non-food production land were combined and based on a 95% protection level, as there were insufficient data to be able to separately calculate Eco-SGVs for plants and invertebrates.

F3 and F4 toxicity data were available for fine and coarse grained soils. Fine-grained soils are those which contain greater than 50% by mass of particles less than 75 μm mean diameter. Coarse-grained soils are those which contain greater than 50% by mass of particles greater than 75 μm mean diameter. However, there were insufficient data available to use an SSD approach, and CCME (2008a) used a ranked response distribution, which ranks the response relative to controls for a range of species/endpoints for F3. For agricultural/residential land the SQG was based on 25th percentile if it showed a response of at least 75% of the control response. For commercial/industrial land use the SQG was based on 50th percentile of the RRD showing a response of at least 75% of the control response. For F4, the SQG for agricultural/residential land and commercial land was based on the 25th and 50th percentile of plant and invertebrate EC20/25 toxicity data, respectively. Warne (2010a) recommended that the Canadian SQG for F3 and F4 be adopted but be considered as low reliability EILs, given the paucity of available data and the methodology used. These values are similarly recommended for use as Eco-SGVs, noting that only the F3 fraction is effectively captured under the current New Zealand analysis scheme.

Given the absence of data on the toxicity of aged contamination, these Eco-SGVs are considered relevant for fresh contamination only. An exception is for the F3 fraction, which is predominantly derived from weathered hydrocarbon contamination (CCME 2008a). This is also the fraction that tends to dominate aged TPH concentrations.

Finally, in recognition of the limited data used to develop these Eco-SGVs, and the variable composition of TPH, these Eco-SGVs are considered most appropriate for use as screening criteria.

Table 49 SQGs for TPH fractions F1 and F2 derived in this study (Eco-SGV), and by Warne (2010a) and CCME (2008a)

Source	Ecologically sensitive areas 99% protection	Agriculture/non-food production land 95% protection	Residential and recreational areas 80% protection	Commercial and industrial 60% protection
F1				
This study[1]	66	110	130	170
Warne 2010a	126	-	180	217
CCME 2008a	-	-	210	320
F2				
This study[1]	45	70	110	140
Warne 2009	23	-	118	172
CCME 2008	-	-	150	260

[1]Values are rounded

Table 50 Recommended Eco-SGVs for fractions F3 and F4

Fraction and soil type	Recommended Eco-SGVs			
	Ecologically sensitive areas	Agriculture/non-food production land	Residential and recreational	Commercial and industrial
F3 (fine)	na	1300	1300	2500
F3 (coarse)	na	300	300	1700
F4 (fine)	na	2500	2500	6600
F4 (coarse)	na	1700	1700	3300

Na not available

4.11 Polycyclic aromatic hydrocarbons

As with TPH, polycyclic aromatic hydrocarbons (PAHs) are a large family of compounds. PAHs occur naturally in crude oil, creosote, coal tar, and coal and are also produced from incomplete combustion of organic matter including fossil fuels and wood. Polycyclic aromatic hydrocarbons are ubiquitous in the environment and generally occur in complex mixtures.

4.11.1 Toxicity data

Establishing ecological soil criteria for PAHs is challenging given the number of different compounds and the fact that they typically occur in mixtures. The Canadian Council of Ministers for the Environment (CCME 2008b) provide a comprehensive discussion of the toxicity of PAHs in the soil environment, and compile toxicity data for a range of PAHs. In an earlier study, Kaputska (2004a) conducted an extensive review of the literature to assist in the development of the Eco-SSLs (ecological soil screening levels) for PAHs for the United States Environmental Protection Agency (US EPA) and found only four papers

passed the criteria for inclusion in developing Eco-SSLs, although more data are available in the final US EPA documents (US EPA 2007e). Nonetheless, data overall remain limited. The CCME (2008b) developed criteria for all PAHs for which there were sufficient data (anthracene, fluoranthene and benzo(a)pyrene). The US EPA (2007e) developed some criteria for low molecular weight and high molecular weight PAHs

For the current work, Eco-SGVs were developed for fluoranthene and benzo(a)pyrene (BaP). Fluoranthene is a low molecular weight PAH that may often present at higher concentrations relative to other PAHs, while BaP is a well-recognised high molecular weight PAH that is often of toxicological concern.

There were toxicity data for two species of plants and three species of invertebrates in three taxonomic groups available for fluoranthene (Appendix L). For BaP, in addition to the data provided in CCME (2008b), data from Hund-Rinke and Simon (2005) and Duan et al. (2015) were used. This provided data for four plant species, four invertebrate species and three microbial processes. Further, BaP is a lipopillic compound with an octanol-water partition coefficient >4 and is therefore considered to biomagnify. Thus ACLs accounting for both direct contact and biomagnification need to be derived.

4.11.2 Normalisation and ageing

No data were available to normalise or account for ageing for any of the PAHs considered.

4.11.3 Derived limits

There were toxicity data for two species of plants and three species of invertebrates in three taxonomic groups available for fluoranthene (Appendix L). This meets the bare minimum to use the SSD approach. The sensitivities of the different organisms were overlapping (Figure 12), hence all data were used to derive ACLs. The derived ACLs have very wide confidence limits given the limited amount of data (Table 51), thus they are considered to be of low reliability.

There were toxicity data for four plant species, four invertebrate species and three microbial processes, also meeting requirements for using the SSD approach. The sensitivities of the different organisms were overlapping (Figure 13), hence all data were used to derive ACLs. Thus ACLs were derived for direct contact, and accounting for biomagnification (i.e. ACLs were based on a higher protection levels) (Table 51).

Preliminary estimates of median background concentrations of BaP range from 0.003 mg/kg for rural areas to 0.07 mg/kg for urban areas, thus background concentrations are negligible compared to the ACLs, and the ACLs are effectively the Eco-SGVs.

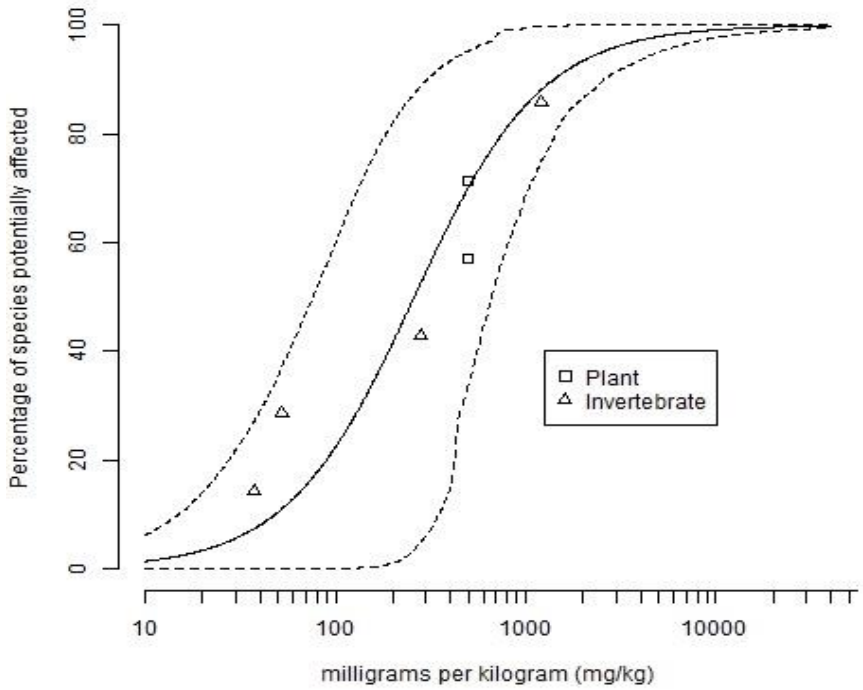

Figure 12 The SSD of 30% effect concentration (EC30) toxicity data for fluroanthene contamination for terrestrial plants and invertebrates.

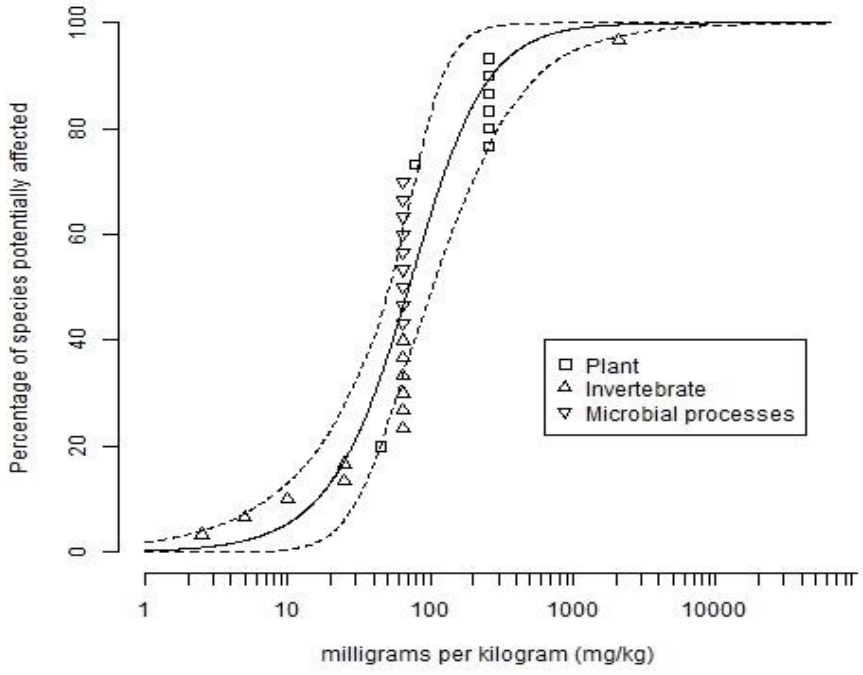

Figure 13 The SSD of 30% effect concentration (EC30) toxicity data for benzo(a)pyrene contamination for terrestrial plants, invertebrates and soil microbial processes.

Table 51 Added concentration limits (ACLs) developed for fluoranthene and benzo(a)pyrene based on LOEC/EC30 toxicity endpoints

Land use	Fluoranthene		Benzo(a)pyrene			
	$ACL_{(EC30)}$ (mg/kg)	$ACL_{(EC30)}$ (mg/kg)	$ACL_{(EC30)}$ (mg/kg)	$ACL_{(EC30)}$ (mg/kg) 95th CI	$ACL_{(EC30\ BM)}$	95th background concentration
Areas of ecological significance	7.6	2 – 181	2.8	0.49 – 22	2.8	0.06 (rural)
Agricultural land/non-food production land	27	8.4 – 262	9.4	3.1 – 30	2.8	0.95 (urban)
Residential/recreational	89	29 – 433	28	16 – 47	22	
Commercial/industrial	190	56 – 569	54	37 – 79	47	

Finally, in recognition of the limited data used to develop these Eco-SGVs, and the variable composition of PAH mixtures, they are considered most appropriate for use as screening criteria.

4.11.4 Comparison with available guidelines

A summary of SQGs for fluoranthene and BaP from various jurisdictions is provided in Table 52. The derivation methodology and purpose of the SQGs shown can be different, and therefore direct comparison with the Eco-SGVs and each other is problematic. The Eco-SGVs for fluoranthene were similar to the Canadian SQGs for the corresponding land uses, and similar to the US Eco-SSLs. The Australian EILs for BaP are based on previous Canadian SQGs. The EILs for areas of ecological significance and urban residential were similar to the SQG-food ingestion of the more recently derived Canadian values for agriculture and residential land use. The Canadian SQG-food ingestion was based on the most sensitive receptor, which was an American robin exposed via bioaccumulation in worms, which in turn was estimated by physical properties as opposed to any measured values. While biomagnification has been accounted for in the derivation of EcoSGVs for BaP, these are still higher than the Canadian SQG. However, as noted earlier (section 3.2.10), worms and other soil invertebrates form only a minor part of the diet for most New Zealand birds, thus biomagnification would be expected to be lower.

Table 52 Soil quality guidelines for fluoranthene and benzo(a)pyrene (BaP) from international jurisdictions

Jurisdiction	Name of value	Numerical value (mg/kg)		Source
		Fluoroanthene	BaP	
Australia	EILs			Warne 2010b
	Areas of ecological significance (fine and coarse) (BaP)	-	0.7	
	Urban residential/public open space (BaP)	-	0.7	
	Commercial/industrial	-	1.4	
Canada	SQG-food ingestion Agricultural/residential	15.4	0.6	CCME 2008b
	SQG-soil contact Agricultural/residential	50	20	
	SQG-soil contact commercial/industrial - BaP	180	72	
US		LMW[1]	HMW[2]	US EPA 2007e
	Eco-SSL plants	NA	NA	
	Eco-SSL invertebrates	29	18	
	Eco-SSL avian	NA	NA	
	Eco-SSL mammalian	100	1.1	
Denmark	Ecotoxicological soil quality criteria		1.0	Carlon 2007

[1]Fluoranthene is a low molecular weight (LMW) PAH
[2] BaP is a high molecular weight (HMW) PAH.

5 Summary

The report has presented a methodology for deriving soil guideline values (Eco-SGVs) that are protective of microbial processes, plants, soil invertebrates, wildlife and livestock in New Zealand. This methodology was developed in consultation with stakeholders to facilitate the development of Eco-SGVs that are suitable for use. A user guide (Cavanagh 2016) accompanies this technical document, and a further report provides the technical background to the determination of background soil concentrations across New Zealand (Cavanagh et al. 2015). This methodology was used to develop Eco-SGVs for eleven contaminants (arsenic, boron, cadmium, chromium, fluorine, and lead (Table 53); copper, and zinc (Table 54); TPH, DDT and PAHs (Table 55)). These substances were selected as they have a variety of physicochemical properties and, as a result, behave differently in the environment. Contaminants selected include the most common contaminants as well as contaminants for which toxicity to livestock (fluoride) or bioaccumulation in wildlife (DDT) need also to be considered.

The Eco-SGVs developed for use are predominantly based on the LOEC/EC30 toxicity endpoint for aged contamination. For all inorganic contaminants sufficient data were available to use the SSD approach to derive ACLs. These were added to the range in median background concentrations for the different elements determined by Cavanagh et al. (2016) except for B, which is based on hot-water soluble boron concentrations and for which the contribution from background B concentrations is expected to be negligible.

Relationships to normalise toxicity data to soil properties were available for microbes, plants, and soft-bodied and hard-bodied invertebrates for Cu and Zn, thus Eco-SGVs were able to be developed for the three New Zealand reference soils (Table 53). As Cu and Zn present in urban stormwater, which may be discharged to land, is in a form similar to that in freshly spiked soils, Eco-SGVs for fresh and aged contamination were developed for Cu and Zn. For Cr, normalisation relationships were only available for soft-bodied invertebrates although this made no practical difference to ACLs derived for the three New Zealand reference soils so only one generic set of Eco-SGVs was developed. Generic ACLs were developed for As, B, Cd, and Pb and are considered applicable to all soil types for the appropriate land use. Provisional ACLs were also developed for F, however given the uncertainty of the estimates, they are not recommended for use. As Cd biomagnifies in the food chain, Eco-SGVs are based on a higher protection level compared to non-biomagnifying contaminants. While Pb is not considered to biomagnify per se, there may be potential for secondary poisoning to occur at higher Pb concentrations; thus for the residential/recreational and commercial/industrial land uses, Eco-SGVs based on a higher level of protection are recommended.

There were limited toxicity data available for the organic contaminants. Utilisation of older studies (i.e. pre-1970) yielded additional data for DDT, and sufficient to use the SSD approach for deriving ACLs. The main residue typically present in soils as a result of the historical use of DDT is DDE, the main degradation product of DDT. However, a dearth of data on the toxicity of DDE to soil microbes, plants and invertebrates precludes the development of an Eco-SGV for DDE. To address this, and given the observation of marked biomagnification of DDE in a New Zealand food chain, more conservative DDT Eco-SGVs were recommended for use. In this case, the Eco-SGVs were based on the NOEC/EC10 toxicity endpoints, and accounted for biomagnification (i.e. a higher protection level was used to set the Eco-SGV).

Eco-SGVs are developed for TPH and PAHs (fluoranthene, benzo(a)pyrene). These values are recommended for use as screening criteria only as these compounds are typically present as mixtures of varying composition, and therefore toxicity, and they are based on limited toxicity data.

Table 53 Eco-SGVs$_{(EC30)}$ developed for arsenic (As), boron (B), cadmium (Cd), chromium (Cr), and lead (Pb) for the lowest median background concentration. Eco-SGVs should be based on background concentrations relevant to the site[1] under assessment and are considered applicable to all soil types

Land use (% protection)	As Eco-SGV[2]$_{(EC30)}$ (mg/kg)	B Eco-SGV[3]$_{(EC30)}$ (mg/kg)	Cd Eco-SGV$_{BM}$[4] (mg/kg)	Cr Eco-SGV[5]$_{(EC30)}$ (mg/kg)	Pb Eco-SGV[6]$_{(EC30)}$ (mg/kg)
Areas of ecological significance (99%)	6	4	1.5	100	55
Non-food production land (95%)	20	7	1.5	190	280
Agricultural land (95% plants, 80% microbes and invertebrates)	20	6	1.5	300	530
Residential/recreational area (80%)	60	15	12	390	900[7]
Commercial/industrial (60%)	150	15	33	650	2500[7]

[1]This may be the median background concentration for the relevant geological grouping obtained from https://lris.scinfo.org.nz/, or other site-specific information, if available

[2] Median background concentration range: 2.2-4 mg/kg

[3] Hot-water soluble B; background B concentrations are expected to be negligible although low concentrations (1-3 mg/kg) are typical for agricultural soils to which B may have been added for agronomic purposes

[4]Median background concentration range: 0.05-0.1mg/kg; BM – biomagnification, an extra 5% protection applied to each landuse

[5]Median background concentration range: 9-27 mg/kg

[6] Median background concentration range: 7-15 mg/kg

[7] extra protection due to potential for secondary poisoning at higher soil concentrations

Table 54 Eco-SGVs developed for fresh and aged copper (Cu) and zinc (Zn) contamination in the three New Zealand reference soils, using the lowest median background concentration for Cu and Zn[1]. Eco-SGVs should be based on background concentrations relevant to the site under assessment[2]. The fresh values are applicable where discharge of stormwater or non-organic liquid wastes onto soil is being assessed

Land use[3]	Cu Eco-SGV$_{(EC30)}$ Typical soil		Cu Eco-SGV$_{(EC30)}$ Sensitive soil		Cu Eco-SGV$_{(EC30)}$ Tolerant soil		Zn Eco-SGV$_{(EC30)}$ Typical soil		Zn Eco-SGV$_{(EC30)}$ Sensitive soil		Zn Eco-SGV$_{(EC30)}$ Tolerant soil	
	fresh	aged	fresh	aged	fresh	aged	fresh	aged	fresh	aged	fresh	aged
Areas of ecological significance (99%)	25	45	25	45	25	45	50	120	60	110	70	160
Non-food production land (95%)	55	100	45	85	65	120	800	170	75	150	95	230
Agricultural land (95% plants, 80% microbes and invertebrates)	110	220	80	150	170	340	95	190	75	130	120	265
Residential/recreational area (80%)	120	240	95	180	170	340	130	300	90	260	160	380
Commercial/industrial (60%)	220	420	160	320	320	630	210	480	110	430	250	620

[1]Median background concentration range for Cu: 7 – 25 mg/kg; Median background concentration range for Zn: 24 – 44 mg/kg.

[2] This may be the median background concentration for the relevant geological grouping obtained from https://lris.scinfo.org.nz/, or other site-specific information, if available

Table 55 Eco-SGVs (mg/kg) developed for organic contaminants

Land use	Total petroleum hydrocarbons (TPH)[1]						DDT	Polycyclic aromatic hydrocarbons (PAH)	
	F1	F2	F3		F4			Fluoranthene	Benzo(a)pyrene
			Fine[2]	Coarse[3]	Fine	Coarse			
Areas of ecological significance (99%)	66	45	-	-	-		1.1	7.6	2.8
Non-food production land (95%)	110	70	1300	300	2500	1700	2.4	27	2.8
Agricultural land (95% plants, 80% microbes and invertebrates)	110	70	1300	300	2500	1700	1.9	27	2.8
Residential/recreational area (80%)	130	110	1300	300	2500	1700	4.8	89	22
Commercial/industrial (60%)	170	140	2500	1700	6600	3300	11	190	47

[1] F1: C7–C9, F2: >C9–C15, F3: >C15–C36 and F4: >C36; see also Cavanagh and Munir (2016), section 4.10.

[2] Fine-grained soils are those which contain greater than 50% by mass of particles less than 75 μm (mean diameter).

[3] Coarse-grained soils are those which contain greater than 50% by mass of particles greater than 75 μm mean diameter.

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Appendix A – Background concentrations

Table 56 Predicted background concentrations (median and 95th quantile estimates) for arsenic, cadmium and copper in each of the Chemical4 factor levels. n = number of samples. Estimated concentrations for sub-groups with n <30 are considered less reliable and for n <10, unreliable

Arsenic				Cadmium				Copper			
Chemical4 Factor	**n**	**median**	**95%**	**Chemical4 Factor**	**n**	**median**	**95%**	**Chemical4 Factor**	**n**	**median**	**95%**
gravel	393	2.88	12.06	gravel	101	0.066	0.34	gravel	229	10.00	42.85
SandStnPakihi	137	3.03	12.67	SandStn	43	0.061	0.31	SandStn	131	14.19	60.85
SandStn	131	2.81	11.77	SandStnPakihi	38	0.054	0.28	CongMaui	109	11.05	47.36
CongMaui	109	2.64	11.04	greywacke	36	0.059	0.30	SandStnPakihi	80	9.37	40.17
ignimbrite	91	3.91	16.38	ignimbrite	31	0.096	0.49	Sch	73	7.69	32.95
MudStnPakihi	87	2.38	9.97	MudStn	28	0.091	0.46	MudStn	68	9.76	41.83
Sch	72	2.58	10.80	AltSandStnSiltStnMaui	25	0.041	0.21	AltSandStnSiltStnMaui	56	6.71	28.77
MudStn	65	4.05	16.95	Sch	19	0.016	0.08	ignimbrite	51	9.83	42.16
greywacke	45	3.53	14.76	basalt	18	0.101	0.51	greywacke	38	12.14	52.03
basalt	41	2.12	8.87	andesite	16	0.089	0.45	MudStnPakihi	37	11.23	48.14
AltSandStnSiltStnMaui	37	3.03	12.67	CongMaui	15	0.085	0.43	basalt	35	25.27	108.3
semiSch	34	2.30	9.63	Cong	12	0.065	0.33	semiSch	34	7.28	31.19
andesite	22	3.16	13.24	MudStnPakihi	11	0.065	0.33	sand	28	7.88	33.78
sand	18	8.07	33.77	melange	10	0.069	0.35	andesite	20	14.50	62.17
Cong	17	2.28	9.54	semiSch	10	0.055	0.28	Cong	17	5.82	24.95
rhyolite	15	3.63	15.19	sand	8	0.099	0.50	scoria	16	23.98	102.8
limestone	12	4.14	17.32	limestone	6	0.19	0.97	limestone	11	11.14	47.77
mud	11	4.17	17.47	rhyolite	4	0.27	1.40	tuff	11	19.84	85.05
SiltStn	9	3.45	14.42	breccia	3	0.047	0.24	rhyolite	9	11.92	51.12

Arsenic				Cadmium				Copper			
Chemical4 Factor	**n**	**median**	**95%**	**Chemical4 Factor**	**n**	**median**	**95%**	**Chemical4 Factor**	**n**	**median**	**95%**
melange	6	5.20	21.75	metaSed	3	0.078	0.40	SiltStn	9	16.52	70.82
volcanics	5	3.05	12.75	till	3	0.039	0.20	volcanics	8	10.26	43.98
peat	4	2.49	10.42	agglomerate	2	0.12	0.60	peat	6	12.10	51.89
AltSandStnMudStn	3	3.78	15.82	AltSandStnMudStn	2	0.051	0.26	melange	5	11.88	50.94
breccia	3	5.65	23.64	argillite	2	0.078	0.40	silt	5	8.73	37.42
metaSed	3	0.55	2.28	gabbro	2	0.058	0.30	mud	4	12.63	54.13
till	3	4.79	20.06	mud	2	0.065	0.33	AltSandStnMudStn	3	10.07	43.18
gabbro	2	1.16	4.86	peat	2	0.034	0.18	breccia	3	17.61	75.52
tuff	2	3.42	14.32	tuff	2	0.034	0.18	metaSed	3	6.13	26.29
peridotite	1	1.95	8.18	scoria	1	0.402	2.05	till	3	8.98	38.49
pyroclastics	1	2.36	9.89	silt	1	0.026	0.13	gabbro	2	4.56	19.57
scoria	1	5.03	21.08	tonalite	1	0.07	0.36	fill	1	10.37	44.45
silt	1	2.65	11.08	volcanics	1	0.17	0.84	peridotite	1	15.99	68.55
tonalite	1	1.25	5.23					pyroclastics	1	21.06	90.29
								tonalite	1	30.19	129.4

Table 57 Predicted background concentrations (median and 95th quantile estimates) for chromium and lead in each of the Chemical4 factor levels for which data is available. n = number of samples. Estimated concentrations for sub-groups with n <30 are considered less reliable and for n <10, unreliable

Chromium				Lead			
Chemical4 Factor	**n**	**median**	**95%**	**Chemical4 Factor**	**n**	**median**	**95%**
gravel	556	16.56	80.15	gravel	499	12.20	44.34
SandStnPakihi	172	12.50	60.50	SandStnPakihi	160	8.27	30.08
SandStn	150	12.83	62.07	SandStn	145	10.44	37.96
CongMaui	124	12.57	60.82	CongMaui	116	10.67	38.80
MudStnPakihi	106	11.76	56.88	MudStnPakihi	106	7.11	25.83
ignimbrite	100	13.92	67.35	ignimbrite	99	6.82	24.79
MudStn	94	13.19	63.83	MudStn	80	10.60	38.55
basalt	76	26.56	128.5	Sch	72	10.79	39.23
Sch	73	10.95	53.00	basalt	52	15.50	56.34
AltSandStn/SiltStnMaui	59	8.56	41.39	greywacke	45	10.02	36.43
sand	46	13.98	67.65	sand	43	12.85	46.71
greywacke	45	13.66	66.08	AltSandStn/SiltStnMaui	37	7.18	26.10
semiSch	35	10.80	52.26	semiSch	34	9.35	34.01
andesite	23	10.68	51.67	andesite	23	10.24	37.22
Cong	17	15.01	72.62	Cong	17	10.60	38.52
scoria	17	22.51	108.92	breccia	15	5.78	21.02
breccia	16	17.53	84.80	rhyolite	15	9.10	33.09
rhyolite	15	20.84	100.84	mud	14	14.15	51.45
mud	14	15.26	73.83	limestone	12	10.59	38.49
limestone	12	17.74	85.84	SiltStn	10	11.56	42.01

Chromium				Lead			
Chemical4 Factor	**n**	**median**	**95%**	**Chemical4 Factor**	**n**	**median**	**95%**
tuff	12	27.14	131.3	peat	7	8.79	31.97
SiltStn	10	11.00	53.21	melange	6	77.84	283.0
peat	9	12.45	60.24	volcanics	5	17.76	64.56
volcanics	8	16.00	77.40	agglomerate	3	14.96	54.39
melange	6	54.17	262.1	AltSandStnMudStn	3	5.88	21.37
silt	6	23.99	116.1	metaSed	3	7.26	26.40
agglomerate	4	17.18	83.15	till	3	9.76	35.47
till	4	24.11	116.7	tuff	3	13.86	50.39
AltSandStnMudStn	3	5.66	27.38	gabbro	2	5.92	21.51
metaSed	3	13.06	63.20	silt	2	14.45	52.54
gabbro	2	7.26	35.10	peridotite	1	66.16	240.5
fill	1	16.87	81.62	pyroclastics	1	154.62	562.1
peridotite	1	28.68	138.8	scoria	1	95.38	346.7
pyroclastics	1	20.51	99.26	tonalite	1	5.69	20.68
tonalite	1	6.51	31.50				

Table 58 Predicted background concentrations (median and 95th quantile estimates) for nickel and zinc in each of the Chemical4 factor levels for which data is available. n = number of samples. Estimated concentrations for sub-groups with n <30 are considered less reliable and for n <10, unreliable

Nickel				Zinc			
Chemical4 Factor	**n**	**median**	**95%**	**Chemical4 Factor**	**n**	**median**	**95%**
gravel	539	7.98	44.96	gravel	99	44.06	182.8
SandStnPakihi	162	5.83	32.88	SandStn	44	34.50	143.1
SandStn	150	6.10	34.38	SandStnPakihi	38	24.53	101.8
CongMaui	122	5.93	33.42	ignimbrite	32	31.25	129.7
ignimbrite	100	5.99	33.75	MudStn	31	27.02	112.1
MudStnPakihi	100	6.24	35.15	greywacke	27	29.35	121.8
MudStn	82	6.96	39.21	AltSandStn/SiltStnMaui	25	19.68	81.66
Sch	73	4.71	26.52	basalt	20	71.29	295.8
basalt	72	13.74	77.43	Sch	19	31.70	131.5
greywacke	45	5.30	29.86	andesite	16	44.59	185.0
sand	38	4.88	27.49	CongMaui	15	46.03	191.0
AltSandStn/SiltStnMaui	37	5.16	29.07	sand	15	34.86	144.7
semiSch	35	4.36	24.58	Cong	11	24.43	101.4
andesite	22	6.38	35.98	MudStnPakihi	11	23.61	97.97
Cong	17	4.97	28.02	semiSch	7	24.86	103.2
breccia	16	5.61	31.60	limestone	5	53.93	223.8
rhyolite	15	10.19	57.44	melange	5	22.71	94.24
mud	14	8.85	49.90	rhyolite	4	38.55	160.0
limestone	12	9.36	52.78	breccia	3	49.88	207.0
SiltStn	10	5.81	32.74	metaSed	3	23.69	98.29

Nickel				Zinc			
Chemical4 Factor	**n**	**median**	**95%**	**Chemical4 Factor**	**n**	**median**	**95%**
volcanics	8	8.42	47.45	AltSandStnMudStn	2	20.91	86.77
peat	7	7.60	42.83	gabbro	2	13.03	54.05
melange	6	14.92	84.10	mud	2	45.92	190.5
agglomerate	4	3.99	22.49	peat	2	26.73	110.9
till	4	5.33	30.02	tuff	2	55.93	232.1
AltSandStnMudStn	3	1.92	10.83	agglomerate	1	35.60	147.7
metaSed	3	5.24	29.55	scoria	1	409.09	1697.5
gabbro	2	1.90	10.69	silt	1	40.26	167.0
silt	2	17.29	97.44	till	1	52.95	219.7
tuff	2	11.92	67.18	tonalite	1	34.54	143.3
peridotite	1	21.67	122.2	volcanics	1	26.74	110.9
pyroclastics	1	27.38	154.3				
scoria	1	20.06	113.1				
tonalite	1	3.01	16.95				

Appendix B – Raw data for Arsenic

Table 59 Arsenic toxicity data, including converted values, used to generate Eco-SGVs

Scientific name	Toxicity endpoint	ALF	EC10 (mg/kg)	Final EC10 (mg/kg)	EC20/30 (mg/kg)	Final EC30 (mg/kg)	Category	EC50 (mg/kg)	NOEC (mg/kg)	LOEC	References
Triticum aestivum	Seedling growth	2	76	152	190	380	3	380	200		Yoon et al. 2015
Triticum aestivum	Seedling growth	2	320	640	800	1600	5	1600	320		Yoon et al. 2015
Lactuca sativa	Root elongation		156.4	156.4	391	391	2	426.5	200		Cao et al. 2009a
Lactuca sativa	Root elongation		20.4	20.4	51	51	2	123.7	40		Cao et al. 2009a
Lactuca sativa	Root elongation		30.47	30.47	76.175	76.175	2	64.8	<40		Cao et al. 2009a
Lactuca sativa	Root elongation		21.38	21.38	53.45	53.45	2	59.3	<40		Cao et al. 2009a
Lactuca sativa	Root elongation		71.89	71.89	179.725	179.725	2	104.3	60		Cao et al. 2009a
Lactuca sativa	Root elongation		79.73	79.73	199.325	199.325	2	185.5	90		Cao et al. 2009a
Cucumis sativus	Seedling growth	2	200	400	500	1000	5	356	200		Yoon et al. 2015
Cucumis sativus	Seedling growth	2	80	160	200	400	5	377	80		Yoon et al. 2015
Phaseolus radiatus	Seedling growth	2	5	10	12.5	25	5	21	5		Yoon et al. 2015
Phaseolus radiatus	Seedling growth	2	40	80	100	200	5	75	40		Yoon et al. 2015
Brassica campestris var. chinensis	Seedling growth	2	125	250	312.5	625	5	>125	125		Yoon et al. 2015
Brassica oleracea	Seedling growth	2	150	300	375	750	5	>150	150		Yoon et al. 2015
Brassica nigra	Seedling growth	2	200	400	500	1000	5	>200	200		Yoon et al. 2015
Brassica campestris	Seedling growth	2	200	400	500	1000	5	>200	200		Yoon et al. 2015
Pisum sativum	Seedling growth	2	200	400	500	1000	5	340	200		Yoon et al. 2015
Sorghum bicolor	Seedling growth	2	500	1000	1250	2500	5	>500	500		Yoon et al. 2015
Sorghum bicolor	Seedling growth	2	320	640	800	1600	5	591	320		Yoon et al. 2015
Hordeum vulgare	Seedling growth	2	200	400	500	1000	5	>500	200		Yoon et al. 2015
Hordeum vulgare	Root elongation	2	71.2	1424	178	356	3	200.4	15	30	Song et al. 2006
Hordeum vulgare	Root elongation	2	148	296	370	740	3	419.6	15	30	Song et al. 2006

Scientific name	Toxicity endpoint	ALF	EC10 (mg/kg)	Final EC10 (mg/kg)	EC20/30 (mg/kg)	Final EC30 (mg/kg)	Category	EC50 (mg/kg)	NOEC (mg/kg)	LOEC	References
Hordeum vulgare	Root elongation	2	11.8	23.6	29.5	59	3	44.9	-	15	Song et al. 2006
Hordeum vulgare	Root elongation	2	28.8	57.6	72	144	3	71.4	30	60	Song et al. 2006
Hordeum vulgare	Root elongation	2	20.1	40.2	50.25	100.5	3	46.1	15	30	Song et al. 2006
Hordeum vulgare	Root elongation	2	58.3	116.6	145.75	291.5	3	205	-	15	Song et al. 2006
Hordeum vulgare	Root elongation	2	11.4	22.8	28.5	57	3	28.5	-	15	Song et al. 2006
Hordeum vulgare	Root elongation	2	18.8	37.6	47	94	3	35.7	-	15	Song et al. 2006
Hordeum vulgare	Root elongation	2	50.7	101.4	126.75	253.5	3	240.4	-	15	Song et al. 2006
Hordeum vulgare	Root elongation	2	49.3	98.6	123.25	246.5	3	131.1	-	15	Song et al. 2006
Hordeum vulgare	Root elongation	2	13.9	27.8	34.75	69.5	3	56	-	15	Song et al. 2006
Hordeum vulgare	Root elongation	2	27.7	55.4	69.25	138.5	3	195.4	-	15	Song et al. 2006
Hordeum vulgare	Root elongation		16.3	16.3	40.75	40.75	3	75.6	-		Song et al. 2006
Hordeum vulgare	Root elongation		106.8	106.8	267	267	3	229.2	-		Song et al. 2006
Hordeum vulgare	Root elongation		489	489	1222.5	1222.5	3	1025.8	-		Song et al. 2006
Hordeum vulgare	Root elongation		704	704	1760	1760	3	1165.3	-		Song et al. 2006
Glycine max	Shoot growth	2	60	120	150	300	3	300	60		Cao et al. 2009b
Phaseolus vulgaris	Yield		4	4	10	10	1	20		10	Woolson 1973
Phaseolus vulgaris	Yield		10	10	25	50	1	50	10	50	Woolson 1973
Phaseolus vulgaris	Yield		4	4	10	10	1	20		10	Woolson 1973
Phaseolus lunatus	Yield		0	10	25	25	2	0	10		Woolson 1973
Phaseolus lunatus	Yield		50	50	125	125	2	250	50		Woolson 1973
Phaseolus lunatus	Yield		0	10	25	25	2	0	10		Woolson 1973
Zea mays	Yield	2	100	200	250	500	1	500	100	500	Woolson 1972
Spinacia oleracea	Yield		4	4	10	10	1	20		10	Woolson 1973
Spinacia oleracea	Yield		10	10	25	50	1	50	10	50	Woolson 1973
Spinacia oleracea	Yield		4	4	10	10	1	20		10	Woolson 1973

Scientific name	Toxicity endpoint	ALF	EC10 (mg/kg)	Final EC10 (mg/kg)	EC20/30 (mg/kg)	Final EC30 (mg/kg)	Category	EC50 (mg/kg)	NOEC (mg/kg)	LOEC	References
Brassica oleracea var. capitata	Yield		50	50	125	125	5	250	50		Woolson 1973
Brassica oleracea var. capitata	Yield		100	100	250	250	5	500	100		Woolson 1973
Brassica oleracea var. capitata	Yield		20	20	50	50	1	100		50	Woolson 1973
Solanum lycopersicum	Yield		40	40	100	100	4	200		100	Woolson 1973
Solanum lycopersicum	Yield		100	100	250	250	5	500	100		Woolson 1973
Solanum lycopersicum	Yield		40	40	100	100	1	0		100	Woolson 1973
Raphanus sativus	Yield	2	12	24	30	60		120			Sheppard et al 1982
Lolium perenne	Dry matter growth	2	9.2	18.4	23	46	1	71			Anderson & Basta 2009
Lolium perenne	Dry matter growth	2	15.6	31.2	39	78	1				Anderson & Basta 2009
Lolium perenne	Dry matter growth	2	18.8	37.6	47	94	1	98			Anderson & Basta 2009
Lolium perenne	Dry matter growth	2	16.4	32.8	41	82	1	84			Anderson & Basta 2009
Lolium perenne	Dry matter growth	2	42	84	105	210	1	171			Anderson & Basta 2009
Panaicum milliaceum	Decrease shoot weight	2	40	80	100	200.0			<100	100	Landcare Research 2003
Eisenia fetida	Mortality*	2	20	8	50	20	2	100			Langdon et al. 2003
Lumbricus rubellus	Juvenile mortality*	2	13.4	5.4	13.4	67	3	67			Anderson et al. 2013
Lumbricus terrestris	Mortality*	2	20	8	50	20	3	100			Meharg et al. 1998
Lumbricus terrestris	Mortality*	2	80	32	200	80	3	400			Meharg et al. 1998
Porcellio scaber	Growth	2	400	800	1000	2000.0			400	>400	Landcare Research 2003
Aporrectodea caliginosa	Growth, juveniles	2	40	80	60	120.0			40	60	Landcare Research 2003
Eisenia andrei	Reproduction	2	45	90	112.5	225	2	60			Romero-Freire et al. 2015a
Eisenia andrei	Reproduction	2	82	164	205	410	2	151			Romero-Freire et al. 2015a
Eisenia andrei	Reproduction	2	26	52	65	130	2	56			Romero-Freire et al. 2015a

Scientific name	Toxicity endpoint	ALF	EC10 (mg/kg)	Final EC10 (mg/kg)	EC20/30 (mg/kg)	Final EC30 (mg/kg)	Category	EC50 (mg/kg)	NOEC (mg/kg)	LOEC	References
Eisenia andrei	Reproduction	2	59	118	147.5	295	2	96			Romero-Freire et al. 2015a
Folsomia candida	Reproduction	2	1	2	2.5	5		2.2			Crouau et al. 2015
Microbial Processes	Aryl sulphatase	2	1873	3746	4682.5	9365	5				Al-Khafaji & Tabatabai 1979
Microbial Processes	Aryl sulphatase	2	1873	3746	4682.5	9365	2				Al-Khafaji & Tabatabai 1979
Microbial Processes	Aryl sulphatase	2	1873	3746	4682.5	9365	2				Al-Khafaji & Tabatabai 1979
Microbial Processes	Aryl sulphatase	2	1873	3746	4682.5	9365	5				Al-Khafaji & Tabatabai 1979
Microbial Processes	N mineralisation	2	374.6	749.2	936.5	936.5	5				Liang & Tabatabai 1977
Microbial Processes	N mineralisation	2	374.6	749.2	936.5	936.5	5				Liang & Tabatabai 1977
Microbial Processes	N mineralisation	2	374.6	749.2	936.5	936.5	5				Liang & Tabatabai 1977
Microbial Processes	N mineralisation	2	374.6	749.2	936.5	936.5	5				Liang & Tabatabai 1977
Microbial Processes	Acid-phosphatase	2	1873	3746	4682.5	9365	2				Juma & Tabatabai 1978
Microbial Processes	Acid-phosphatase	2	1873	3746	4682.5	9365	2				Juma & Tabatabai 1978
Microbial Processes	Acid-phosphatase	2	1873	3746	4682.5	9365	2				Juma & Tabatabai 1978
Microbial Processes	Alkaline phosphatase	2	374.6	749.2	936.5	1873	3	1873			Juma & Tabatabai 1978
Microbial Processes	Nitrification	2	1500		3750						Liang &Tabatabai 1977
Microbial Processes	Nitrification	2	1500		3750						Liang &Tabatabai 1977

*acute-chronic ratio of 5 applied to mortality data

Appendix C – Raw data for Boron

Table 60 Raw and converted toxicity data used to calculate ACLs for boron

Scientific name	Toxicity endpoint	EC10 mg/kg	EC10 B mg B/kg	EC20/30	EC20/30 mg B/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Lycopersicon esculentum	Shoot DW	4	4	10	10	1	20	4	10	7.61	1.07			Gunes et al. 1999
Cucumis sativus	Dw	4	4	10	10	1	20	4	10	7.62	1.81			Alpaslan & Gunes 2001
Avena sativa	Shoot length	62	10	154	25	3	308	61.6	154					Becker et al. 2011
Brassica napus	Biomass	35	6	88	14	3	175	35	87.5					Becker et al. 2011
Arachis hypogaea	Shoot dry biomass	8	8	20	20	2	16	8	20	7.34			6.25	Cikili et al. 2015
Triticum aestivum	DM yield	4	4	10	10	1	20	4	10	8.1			0.05	Singh et al. 1990
Hordeum vulgare	Root elongation	27	27	68	68	2	87			4.4		20	31	Mertens et al. 2011
Hordeum vulgare	Root elongation	3	3	8	8	2	13			5.2		2	1.8	Mertens et al. 2011
Hordeum vulgare	Root elongation	16	16	40	40	2	52			6.3		27	3.6	Mertens et al. 2011
Hordeum vulgare	Root elongation	9	9	23	23	2	30			6.7		12	0.9	Mertens et al. 2011
Hordeum vulgare	Root elongation	19	19	48	48	2	51			6.8		33	0.6	Mertens et al. 2011
Hordeum vulgare	Root elongation	14	14	35	35	2	42			7.3		10	2.8	Mertens et al. 2011
Hordeum vulgare	Root elongation	17	17	43	43	2	36			7.8		11	3.6	Mertens et al. 2011
Hordeum vulgare	Root elongation	8	8	20	20	2	25			5		13	2.1	Mertens et al. 2011
Hordeum vulgare	Root elongation	9	9	23	23	2	29			4.5		2	1.5	Mertens et al. 2011
Hordeum vulgare	Root elongation	11	11	28	28	2	27			5.2		19	1.2	Mertens et al. 2011
Hordeum vulgare	Root elongation	18	18	45	45	2	48			6.8		14	1.6	Mertens et al. 2011
Hordeum vulgare	Root elongation	17	17	43	43	2	46			6		17	2.9	Mertens et al. 2011
Hordeum vulgare	Root elongation	19	19	48	48	2	40			4.4		10	4.1	Mertens et al. 2011
Hordeum vulgare	Root elongation	8	8	20	20	2	23			7.1		19	5.1	Mertens et al. 2011
Hordeum vulgare	Root elongation	13	13	33	33	2	32			7		9.6	0.73	Mertens et al. 2011

Scientific name	Toxicity endpoint	EC10 mg/kg	EC10 B mg B/kg	EC20/30	EC20/30 mg B/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Hordeum vulgare	Root elongation	4	4	10	10	2	14			7.2		2.1	0.14	Mertens et al. 2011
Hordeum vulgare	Root elongation	20	20	50	50	2	53			7.5		31.1	0.8	Mertens et al. 2011
Lens culinaris	Shoot DW	10	10	25	25	1	50	10	25					Yau & Erskine 2000
Brassica rapa	Shoot DM	10	10	26	26	1, 5, 3, 3	52	10	26	8				Kaur et al. 2006
Caenorhabditis elegans	Reproduction	149	25	374	62	3	747	149.4	373.5					Becker et al. 2011
Dendrodrilus rubidus	Reproduction	19	19	47	47									AERSD 2015
E andrei	Reproduction	11	11	28	28									AERSD 2015
E.andrei	Reproduction	5	5	12	12									AERSD 2015
Eisenia fetida	Reproduction	97	16	242	40	3	484	96.8	242					Becker et al. 2011
Enchytraeus albidus	Reproduction	22	4	56	9	1	104	22.48	56.2	5.5	3.9	6		Amorim et al. 2012
Enchytraeus crypticus	Reproduction	44	7	110	18	3	220	44	110			20		Becker et al. 2011
Enchytraeus luxuriosus	Reproduction	46	8	114	19	3	228	45.6	114			20		Becker et al. 2011
Folsomia candida	Reproduction	49	8	124	20	2	90.8	49.4	123.5					Krogh 2009
Folsomia candida	Reproduction	15	3	39	6	1	54	15.48	38.7	6		20		Amorim et al. 2012
Folsomia candida	Reproduction	11	11	27	27									AERSD 2015
Folsomia fimetaria	Reproduction	36	6	91	15	2	107	36.4	91					Krogh 2009
Folsomia fimetaria	Reproduction	5	5	13	13									AERSD 2015
Folsomia fimetaria	Reproduction	6	6	15	15									AERSD 2015
Microbial processes	Nitrate formation	480	79	1200	198	3	2400	480	1200					Becker et al. 2011
Oppia nitens	Reproduction	18	18	44	44									AERSD 2015
Oppia nitens	Reproduction	5	5	13	13									AERSD 2015
Poecilus cupreus	Food uptake	268	44	671	111	3	1342	268.4	671					Becker et al. 2011
Prositoma minuta	Reproduction	15	15	37	37									AERSD 2015

Appendix D – Raw data for cadmium

Table 61 Cadmium toxicity data, including converted values, used to generate Eco-SGVs

Scientific name	Toxicity endpoint	EC10 mg/kg	EC20/30 mg/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Triticum aestivum	Shoot elongation	1419.9	2129.85	2	2153.6			6.23	3.86		0.00	Chen et al. 2010
Triticum aestivum	Shoot dry weight	14.3	57.1	2				6.9	1.3	21		Reber 1989
Triticum aestivum	Shoot dry weight	29.0	114	2				7	1.4	3		Reber 1989
Triticum aestivum	Shoot dry weight	7.1	14.3	2				5.6	0.9	7		Reber 1989
Triticum aestivum	Shoot dry weight	3.3	5	4			5	6.7	4			Haghiri 1973
Triticum aestivum	Grain yield	8.7	13	2				7.5				Bingham et al. 1975
Triticum aestivum	Shoot growth	37.7	56.5	3	113	<40		4.3	0.3	21		An 2004
Lactuca sativa	Biomass	4.2	6.25	4	80		6.25	6.6	3	26		da Rosa et al. 2006
Lactuca sativa	Shoot fresh weight	3.2	4.8	5	33	3.2		7.5	1.4			Adema & Herzen 1989
Lactuca sativa	Shoot fresh weight	32.0	48	5	136	32		7.5	1.4			Adema & Herzen 1989
Lactuca sativa	Head weight	8.7	13	2				7.5				Bingham et al. 1975
Lactuca sativa	Shoot dry weight	2.0	32	4	64	2	32	3.9		8		Jasiewicz 1994
Lactuca sativa	Shoot dry weight	1.7	2.5	4	5		2.5	6.7	4			Haghiri 1973
Lactuca sativa	Shoot dry weight	40.0	80	4	260	40	80	4.8	2.6	8.3		Mahler et al. 1978
Lactuca sativa	Shoot dry weight	40.0	160	4	270	40	160	5	2.3	14.6		Mahler et al. 1978
Lactuca sativa	Shoot dry weight	10.0	20	4	100	10	20	5.3	0.9	8.9		Mahler et al. 1978
Lactuca sativa	Shoot dry weight	20.0	80	4	160	20	80	5.7	3	37.5		Mahler et al. 1978
Lactuca sativa	Shoot dry weight	20.0	80	4	195	20	80	7.4	1.4	18.7		Mahler et al. 1978
Lactuca sativa	Shoot dry weight	5.0	10	4	18	5	10	7.7	0.9	40.6		Mahler et al. 1978
Lactuca sativa	Shoot dry weight	2.5	10	4	80	2.5	10	7.5	0.6	4.4		Mahler et al. 1978
Lactuca sativa	Shoot dry weight	10.0	20	4	58	10	20	7.8	0.7	15.2		Mahler et al. 1978

Scientific name	Toxicity endpoint	EC10 mg/kg	EC20/30 mg/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Lolium perenne	Dry matter growth	10.7	16	1	50	10.66667	16	4.78		68.2	4.06	Anderson et al. 2009
Lolium perenne	Dry matter growth	22.0	33	1	87	22	33	5.49		101	7.21	Anderson et al. 2009
Lolium perenne	Dry matter growth	36.0	54	1	84	36	54	6.27		222	14.3	Anderson et al. 2009
Lolium perenne	Dry matter growth	47.3	71	1	221	47.33333	71	7.76		286	6.57	Anderson et al. 2009
Lolium perenne	Dry matter growth	87.3	131	1	406	87.33333	131	6.06		418	23.9	Anderson et al. 2009
Zea mays	Shoot dry weight	1.7	2.5	4	5	1.666667	2.5	6				Miller et al. 1977
Zea mays	Total plant dry weight	3.6	5.4	4								Mench et al.,1989
Zea mays	Yield	12.0	18	1				7.5				Bingham et al. 1975
Zea mays	Shoot growth	89.3	134	3	268	160		4.3	0.3	21		An 2004
Glycine max	Shoot growth	75.3	188.3	3	376.6							Cao et al. 2009b
Glycine max	Bean dry weight	3.3	5	1				7.5				Bingham et al. 1975
Glycine max	Shoot dry weight	1.0	1.5	2	10			4.5	1-20**	0-28**		Miller et al. 1976
Glycine max	Shoot dry weight	6.7	10	1			10	6.1		0-28**		Miller et al. 1976
Glycine max	Shoot dry weight	6.7	10	1			10	7		0-28**		Miller et al. 1976
Glycine max	Shoot dry weight	33.3	50	3	100		100	7.9		0-28**		Miller et al. 1976
Glycine max	Shoot dry weight	10.0	15	2			0	6		28-40**		Miller et al. 1976
Glycine max	Shoot dry weight	6.7	10	1			1	5.5	1-20**	0.28**		Miller et al. 1976
Glycine max	Shoot dry weight	6.7	10	1			1	6.5		0.28**		Miller et al. 1976
Glycine max	Shoot dry weight	10.0	15	2			100	6.1		0.28**		Miller et al. 1976
Glycine max	Shoot dry weight	6.7	10	1			1	5.7		0.28**		Miller et al. 1976
Glycine max	Shoot dry weight	10.0	15	5		10		6.7	4	28-40**		Haghiri, 1973
Lycopersicon esculentum	Shoot growth	50.7	76	1	137.4			5.9±0.09	65.4±4.22 g/kg	3.3		Caetano et al. 2015
Lycosperisicon esculentum	Shoot fresh weight	5.3	8	3	16	>3.2		5.1	3.7			Adema and Herzen 1989

Scientific name	Toxicity endpoint	EC10 mg/kg	EC20/30 mg/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Lycosperisicon esculentum	Shoot fresh weight	57.0	85.5	3	171	32		7.5	1.4			Adema and Herzen 1989
Lycosperisicon esculentum	Fruit	64.0	96	1				7.5				Bingham et al. 1975
Brassica campestris var. *chinensis*	Biomass	33.3	50	4	1100	25	50	6.6	3	26		da Rosa et al. 2006
Avena sativa	Shoot fresh weight	32.3	48.5	3	97	10		5.1	3.7			Adema & Herzen 1989
Avena sativa	Shoot fresh weight	53.0	79.5	3	159	10		7.5	1.4			Adema & Herzen 1989
Avena sativa	Biomass	8.3	12.5	4	115		12.5	6.6	3	26		da Rosa et al. 2006
Avena sativa	Root biomass	6.7	10	4			10					Khan & Frankland 1984
Cucumis sativus	Shoot growth	29.3	44	3	88	40		4.3	0.3	21		An et al. 2004
Raphanus sativus	Root dry weight	6.7	10	4	44		10	5.4		0-15**		Khan and Frankland 1983
Raphanus sativus	Root dry weight	1.7	2.5	4			2.5	6.7	4			Haghiri 1973
Raphanus sativus	Tuber weight	64.0	96	1				7.5				Bingham et al. 1975
Raphanus sativus	Biomass	16.7	25	3	50			6.9	1			Zaman & Zereen 1998
Beta vulgaris	Shoot dry weight	20.0	80		110	20	80	4.8	2.6	8.3		Mahler et al. 1978
Beta vulgaris	Shoot dry weight	20.0	80		135	20	80	5	2.3	14.6		Mahler et al. 1978
Beta vulgaris	Shoot dry weight	40.0	80		110	40	80	5.3	0.9	8.9		Mahler et al. 1978
Beta vulgaris	Shoot dry weight	40.0	80		185	40	80	5.7	3	37.5		Mahler et al. 1978
Beta vulgaris	Shoot dry weight	10.0	160		320	10	160	7.4	1.4	18.7		Mahler et al. 1978
Beta vulgaris	Shoot dry weight	20.0	40		105	20	40	7.5	0.6	4.4		Mahler et al. 1978
Beta vulgaris	Shoot dry weight	40.0	80		195	40	80	7.7	0.9	40.6		Mahler et al. 1978
Beta vulgaris	Shoot dry weight	80.0	160		320	80	160	7.8	0.7	15.2		Mahler et al. 1978

Scientific name	Toxicity endpoint	EC10 mg/kg	EC20/30 mg/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Capsicum frutescens	Pepper dry weight	10.0	15	5		>10		6.7	4			Haghiri 1973
Apium graveolem	Leaf dry weight	10.0	15	5		>10		6.7	4			Haghiri 1973
Picea sitchensis	Root length	1.3	2	4			2	3.3	45	40-100**		Burton et al. 1984
Phaseolus vulgaris	Bean dry weight	26.7	40	1				7.5				Bingham et al. 1975
Cucurbita pepo	Fruit weight	106.7	160	1				7.5				Bingham et al. 1975
Brassica oleracea	Head weight	113.3	170	1				7.5				Bingham et al. 1975
Lepidium sativum	Shoot weight	5.3	8	1				7.5				Bingham et al. 1975
Spinacia oleracea	Shoot weight	2.7	4	1				7.5				Bingham et al. 1975
Brassica rapa	Tuber weight	18.7	28	1				7.5				Bingham et al., 1975
Daucus carota	Tuber weight	13.3	20	1				7.5				Bingham et al. 1975
Sorghum bicolour	Root growth	13.0	19.5		39	20		4.3	0.3	21		An 2004
Folsomia candida	Reproduction	43.5	400		182	266	400	8.2	2	37.2		Bur et al. 2010a
Folsomia candida	Reproduction	56.0	100		111	66	100	4.5	16.5	19.4		Bur et al. 2010a
Folsomia candida	Reproduction	15.0	200		107	133.	200	6.1	1.6	24.8		Bur et al. 2010a
Folsomia candida	Reproduction	26.9	36.1		72.2	24.	36.1	6.0 ± 0.5				Nakamori et al. 2008
Folsomia candida	Reproduction	27.6	41.4	2	158	32	56	6	10	20		Lock & Janssen 2001
Folsomia candida	Reproduction	59.0	88.5	3	177	80		6.0				Herbert et al. 2004
Folsomia candida	Reproduction	196.7	295	3	590			6	10	20		Sandifer & Hopkin 1997
Folsomia candida	Reproduction	43.0	64.5	3	129	76.5	153	6	10	20		Crouau et al. 1999
Folsomia candida	Reproduction	196.7	295	3	590			6	10	20		Sandifer & Hopkin 1996
Folsomia candida	Reproduction	100.0	175.5	3	351	100	150	6.0 ± 0.5		20		Greenslade & Vaughan 2003
Folsomia candida	Reproduction	21.3	32	3	64	21.	32	6	10	20		van Gestel & van Diepen 1997

Scientific name	Toxicity endpoint	EC10 mg/kg	EC20/30 mg/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Folsomia candida	Reproduction	19.3	29	3	58	19	29	6	10	20		van Gestel & van Diepen 1997
Folsomia candida	Reproduction	30.7	46	3	92	31	46	6	10	20		van Gestel & van Diepen 1997
Folsomia candida	Reproduction	24.7	37	3	74	24	37	6	10	20		van Gestel & van Diepen 1997
Folsomia candida	Reproduction	52.0	78	3	156							Crommentujim et al. 1995
Folsomia candida	Reproduction	57.7	86.5	3	173							Crommentujim et al. 1995
Folsomia candida	Reproduction	51.3	77	3	154							Crommentujim et al. 1995
Folsomia candida	Reproduction	41.7	62.5	3	125							Crommentujim et al. 1995
Folsomia candida	Reproduction	49.6						6	10	20		Geomean
Folsomia candida	Reproduction	160.0	240	3	480			4.5	10	20		Sandifer & Hopkin 1996
Folsomia candida	Reproduction	17.0	25.5	3	51			6.1	5.9	20		van Gestel & Hesenbergen 1997
Folsomia candida	Reproduction	180.0	270	3	540			6	10	20		Sandifer & Hopkin 1997
Folsomia candida	Reproduction	260.0	390	3	780			5	10	20		Sandifer & Hopkin 1996
Folsomia candida	Reproduction	37.3	56	3	113			5	10	20		Crouau et al. 2005
Folsomia candida	Reproduction	98.5						5	10	20		Geomean
Folsomia candida	Reproduction	23.5	35.3	3	70.6		35.3	6.19–7.44	10.9	5.2		van Gestel & Mol 2003
Folsomia candida	Reproduction	59.0	88.5	3	113		56.5	5.67	10	20		Crommentujim et al. 1997

Scientific name	Toxicity endpoint	EC10 mg/kg	EC20/30 mg/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Folsomia candida	Reproduction	59.0	88.5	3	306	102	153	7.02	10	20		Crommentujim et al. 1997
Folsomia candida	Reproduction	41.7	62.5	3	125			5.66	2	20		Crommentujim et al. 1997
Folsomia candida	Reproduction	14.7	22	3	44			5.44	3.6	20		Crommentujim et al. 1997
Folsomia candida	Reproduction	27.3	41	3	82			5.65	5.2	20		Crommentujim et al. 1997
Folsomia candida	Reproduction	64.3	96.5	3	193			5.93	6.8	20		Crommentujim et al. 1997
Folsomia candida	Reproduction	43.3	65	3	130			5.85	8.4	20		Crommentujim et al. 1997
Folsomia candida	Reproduction	64.3	96.5	3	193			5.75	10	20		Crommentujim et al. 1997
Folsomia candida	Reproduction	18.1	27.2	3	54.4			6.13–7.36	3	1.4		van Gestel & Mol 2003
Folsomia candida	Reproduction	34.3	51.5	3	103			5.55–6.60	3.5	2.5		van Gestel & Mol 2003
Folsomia candida	Reproduction	14.4	21.65	3	43.3			5.80–6.44	4.2	3.6		van Gestel & Mol 2003
Folsomia candida	Reproduction	205.0	307.5	2	308	180	320	6.3	1.5	17		Lock & Janssen 2001
Folsomia candida	Reproduction	17.6	26.4	2	48.4	18	32	4.4	4.8	1		Lock & Janssen 2001
Folsomia candida	Reproduction	26.9	40.35	2	72.2		36.1	6.0				Nakamori et al. 2008
Sinella communis	Reproduction	12.5	18.75	2	50.1	12.5	18.75	6.0		20		Greenslade & Vaughan 2003
O. yodai	Reproduction	45.8	68.7	2	154.7		77.35	6.0				Nakamori et al. 2008
Sinella umesaoi	Reproduction	26.8	40.2	2	40.9		20.45	6.0				Nakamori et al. 2008
Oppia nitens	Reproduction	45.7	68.5	3	137		68.5	6.0				Owojori et al. 2012

Scientific name	Toxicity endpoint	EC10 mg/kg	EC20/30 mg/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Eisenia fetida	Cocoon production	17.5	26.25	2	55.4	32	56	6.3	1.5	17		Lock & Janssen 2001a
Eisenia fetida	Cocoon production	40.7	61.05	2	73.1	32	56	4.4	4.8	1		Lock & Janssen 2001a
Eisenia fetida	Cocoon production, mortality	48.1	72.15	2	108	56	100	6	10	20		Lock & Janssen 2001a
Eisenia fetida	Cocoon production	15.4	23.15	3	46.3			6.3	10	20		Spurgeon et al. 1994
Eisenia fetida	Cocoon production	98.3	147.5	3	295			6.1	10	20		Spurgeon & Hopkin 1995
Eisenia andrei	Reproduction	25.5	37.3	1	76.4	35	42	5.9	65.4	3.3		Caetano et al. 2016
Eisenia andrei	Cocoon production	11.0	16.5	3	33	18	32	6.7	5.9	20		van Gestel et al. 1991
Eisenia andrei	Cocoon production	6.7	10	4			10	6				van Gestel et al. 1992
Enchytraeus albidus	Reproduction	65.6	98.4	2	158	100	180	6	10	20		Lock & Janssen 2001
Enchytraeus albidus	Reproduction	19.9	29.85	2	72.4	56	100	6.3	1.5	17		Lock & Janssen 2001
Enchytraeus crypticus	Reproduction	2.8	4.15	3	8.3	7	7.7	5.9	65.4	3.3		Caetano et al. 2016
Plectus acuminatus	Juvenile/adult ratio	32.0	160.5	3	321	32	100	5.5	5.9	20		Kammenga et al. 1996
Paronychiurus kimi	Reproduction	20.0	30	3	60	25	50	6.0 ± 0.5		20		Son et al. 2007
Dendrobaena rubida	Cocoon production	6.7	10	4	100		10	4.5	4.5-6.9			Bengtsson et al. 1986
Apporectodea caliginosa	Cocoon production	1.9	2.79	2	35		10	7.05	12.7	20		Khalil et al. 1996b
Microbial processes	Urease activity	646.0	969	2	2409	803	1204.5	8.6		53.6	0.9	Moreno et al. 2003
Microbial processes	Urease activity	31.9	47.8	1	>100.0	>100.0	>100.0	5.9	65.4	3.3		Caetano et al. 2016
Microbial processes	Urease activity	40.0	60	2	120	40	60	7	1.6	2		Doelman & Haanstra 1986
Microbial processes	Urease activity	280.0	420	2	520		260	7.7	2.4	19		Doelman & Haanstra 1986
Microbial processes	Phosphatase activity	123.0	184.5	2	1110	370	555	8.6		53.6	0.9	Moreno et al. 2003
Microbial processes	B - glucosidase activity	553.0	829.5	2	4975		2487.5	8.6		53.6	0.9	Moreno et al. 2003

Scientific name	Toxicity endpoint	EC10 mg/kg	EC20/30 mg/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Microbial processes	Protease activity	108.0	162	2	971		485.5	8.6		53.6	0.9	Moreno et al. 2003
Native soil microflora	SIR	3.6	7.1	1	60	3.6	7.1	6.9	1.3	21		Reber 1989
Native soil microflora	SIR	3.6	7.1	1	70	3.6	7.1	7	1.5	3		Reber 1989
Native soil microflora	SIR	14.3	28.6	1	>228	14.3	28.6	5.6	1	7		Reber 1989
Native soil microflora	SIR	149.3	224	1	1180	50	250	5.2	1.4	0		Saviozzi et al. 1997
Native soil microflora	Nitrification: NO3- production rate -NH4+ substrate	10.0	100	4		10	100	7.43		23.52	5.39	Dusek 1995
Native soil microflora	Nitrification: NO3- production rate -NH4+ substrate	10.0	100	4		10	100	7.6		18.67	2.67	Dusek 1995
Microbial processes	Respiration	266.7	400	4		150	400	7	1.6	2		Doelman & Haanstra 1984
Microbial processes	Respiration	266.7	400	4		150	400	6	5.7	9		Doelman & Haanstra 1984
Microbial processes	Respiration	266.7	400	4		150	400	7.7	2.4	19		Doelman & Haanstra 1984
Microbial processes	Respiration	5333.3	8000	4		3000	8000	7.5	3.2	60		Doelman & Haanstra 1984
Microbial processes	Respiration	666.7	1000	4		400	1000	4.4	12.8	5		Doelman & Haanstra 1984
Native soil microflora	Respiration	246.4	369.6	2	1176			4.5	47	180		Frostegard et al. 1993
Native soil microflora	Respiration	370.9	556.38	2	1180.2			5.2	1.4%C	8		Saviozzy et al. 1997
Native soil microflora	Arylsulphatase activity	28.1	42.15375	2	1016.186			7.5	3.2	60		Haanstra & Doelman 1991
Microbial processes	Arylsulphatase activity	1873.3	2810	1				6.2		29	2.73	Al-Khafaji & Tabatabai 1979

Scientific name	Toxicity endpoint	EC10 mg/kg	EC20/30 mg/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Microbial processes	Arylsulphatase activity	1873.3	2810	1				7.6		30	3.24	Al-Khafaji & Tabatabai 1979
Microbial processes	Arylsulphatase activity	936.7	1405	3	2810			6.5		26	2.91	Al-Khafaji & Tabatabai 1979
Microbial processes	Arylsulphatase activity	936.7	1405	3	2810			7		34	5.32	Al-Khafaji & Tabatabai 1979
Microbial processes	Cell number (survival)	5.0	7.5	5		5		6.5		9		Chaudri et al. 1992
Microbial processes	Cellulase	286.6	429.9	1			13.4	5.9±0.09	65.4	3.3		Caetano et al. 2016
Native soil microflora	ATP content	134.9	168	1	2810.25	112	168					Frostegard et al. 1994
Native soil microflora	ATP content	134.9	168	1	708.183	112	168	7.8	2.6	180		Frostegard et al. 1995
Native soil microflora	Dentrification	6.7	10	4	100	6.7	10	6.7	1.9	0		Bollag and Barabasz 1979
Microbial processes	N mineralisation	374.7	562	1			0	6.5		26	2.91	Liang &Tabatabai 1977
Microbial processes	N mineralisation	374.7	562	1			0	6.6		45	2.95	Liang &Tabatabai 1977
Microbial processes	N mineralisation	374.7	562	1			0	7.6		30	3.24	Liang &Tabatabai 1977
Microbial processes	N mineralisation	374.7	562	1			0	7		34	5.32	Liang &Tabatabai 1977
Microbial processes	N mineralisation	60.5	90.7	1			13.4	5.9±0.09	65.4	3.3		Caetano et al. 2015
Microbial processes	Glutamic acid decomposition	55.0	150	1				7	1.6	2		Haanstra & Doelman 1984
Microbial processes	Glutamic acid decomposition	55.0	150	1				7.7	2.4	19		Haanstra & Doelman 1984
Microbial processes	Glutamic acid decomposition	55.0	400	1				7.5	3.2	60		Haanstra & Doelman 1984

Scientific name	Toxicity endpoint	EC10 mg/kg	EC20/30 mg/kg	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	TOC %	References
Microbial processes	Glutamic acid decomposition	>1000	1500	1				4.4	12.8	5		Haanstra & Doelman 1984
Microbial processes	Nitrification	560.0	840	2								Liang & Tabatabai 1978
Microbial processes	Nitrification	560.0	840	2								Liang & Tabatabai 1978
Microbial processes	Nitrification	560.0	840	2								Liang & Tabatabai 1978
Microbial processes	Acid-phosphatase	93.7	140.5	3	281							Juma & Tatatabai 1978
Microbial processes	Acid-phosphatase	93.7	140.5	3	281							Juma & Tatatabai 1978
Microbial processes	Acid-phosphatase	93.7	140.5	3	281							Juma & Tatatabai 1978
Microbial processes	Alkaline phosphatase	281.0	421.5	2								Juma & Tatatabai 1978
Microbial processes	Alkaline phosphatase	281.0	421.5	2								Juma & Tatatabai 1978
Microbial processes	Phosphatase	8071.0	12106.56	2	9869.598							Doeman & Haanstra 1989
Microbial processes	Phosphatase	829.6	1244.379	2	5305.752							Doeman & Haanstra 1989

Appendix E – Raw data for chromium III

Table 62 Chromium (III) toxicity data, including converted values, used to generate Eco-SGVs

Scientific name	Toxicity endpoint	ALF	EC10 mg/kg	Final EC10	EC20/30	Final EC30	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	References
Agrostis tenuis	Growth	2.5	3333	8333	5000	12 500	4	10 000	3333	5000				Breeze 1973
Avena sativa	Grain yield	2.5	400	1000	600	1500	5		400		5.6	1.6	12	De Haan et al. 1985
Avena sativa	Grain yield	2.5	200	500	300	750	5		200		5.4	2.4	40	De Haan et al. 1985
Avena sativa	Grain yield	2.5	200	500	300	750	5		200		5.2	3.2	58	De Haan et al. 1985
Avena sativa	Grain yield	2.5	400	1000	600	1500	5		400		5	3.4	4	De Haan et al. 1985
Avena sativa	Grain yield	2.5	200	500	300	750	5		200		5.4	6.8	5	De Haan et al. 1985
Avena sativa	Grain yield	2.5	800	2000	1200	3000	5		800		4.6	19.4	4	De Haan et al. 1985
Brassica juncea	Biomass	2.5	500	1250	750	1875	4	1100	500	750				Han et al. 2004
L. sativa	Growth		333	333	500	500	4			500				Sykes et al. 1981
Z. mays	Growth		80	80	320	320	4	640	80	320				Mortvedt & Giordano 1975
Hordeum vulgare	Growth		333	333	500	500	4			500				Sykes et al. 1981
R. sativus	Growth		1000	1000	1500	1500	5		1000					Sykes et al. 1981
Lollium perenne	Growth		333	333	500	500	4			500				Sykes et al. 1981
Brassica rapa chinensis	Root elongation		591	591	887	887	3	1773			7.75	16.33		Wang et al., 2012
Sorghum bicolor × Sorghum sudanense	Shoot		500	667	1000	1000	4	2786.84	500	1000	8.65			López-Luna et al 2009
Sorghum bicolor × Sorghum sudanense	Shoot	2.5	<100	200	100	250	4	1025.06	<100	100	6.7		4	López-Luna et al 2009
Triticum aestivum	Shoot		500	667	1000	1000	4	3643.23	500	1000	8.65			López-Luna et al 2009
Triticum aestivum	Shoot	2.5	500	1250	1000	2500	4	1811.41	500	1000	6.7		4	López-Luna et al 2009
E. andrei	Reproduction	2.5	32	80	100	250	4	200	32	100		6.5	20	van Gestel et al. 1992

Scientific name	Toxicity endpoint	ALF	EC10 mg/kg	Final EC10	EC20/30	Final EC30	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	References
E. fetida	Reproduction	2.5	83	208	125	313	3	250						Molnar et al. 1989
Eisenia fetida	Reproduction	2.5	560	1667	1000	2500	4	892	560	1000		6	20	Lock & Janssen 2002
Enchytraeus albidus	Reproduction	2.5	560	1667	1000	2500	4	637	560	1000		6	20	Lock & Janssen 2002
Folsomia candida	Reproduction	2.5	560	1667	1000	2500	4	604	560	1000		6	20	Lock & Janssen 2002
Microbial process	Arylsulfatase	2.5	433	1083	650	1625	3	1300						Al-khafaji & Tabatabai 1979
Microbial process	Arylsulfatase	2.5	867	2167	1300	3250	4			1300				Al-khafaji & Tabatabai 1979
Microbial process	Arylsulfatase	2.5	433	1083	650	1625	4	1300						Al-khafaji & Tabatabai 1979
Microbial process	Arylsulfatase	2.5	867	2167	1300	3250	4			1300				Al-khafaji & Tabatabai 1979
Microbial process	Arylsulfatase		83	83	125	125		411.2884			7.7	2.4	19	Haanstra & Doelman 1991
Microbial process	Arylsulfatase		276	276	413	413	2	574.5558			7.5	3.2	60	Haanstra & Doelman 1991
Microbial process	Arylsulfatase		2730	2730	4095	4095	2	3202.954			4.4	12.8	5	Haanstra & Doelman,1991
Microbial process	Glutamic acid decomposition		55	55	400	400	4		55	400	7	1.6	2	Haanstra & Doelman 1984
Microbial process	Glutamic acid decomposition		400	400	1000	1000	4		400	1000	7.7	2.4	19	Haanstra & Doelman 1984
Microbial process	Glutamic acid decomposition		55	55	400	400	4		55	400	7.5	3.2	60	Haanstra & Doelman 1984
Microbial process	Glutamic acid decomposition		55	55	400	400	4		55	400	4.4	12.8	5	Haanstra & Doelman 1984
Microbial process	Respiration		150	150	225	225	2				7	1.6	2	Haanstra & Doelman 1984

Scientific name	Toxicity endpoint	ALF	EC10 mg/kg	Final EC10	EC20/30	Final EC30	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	References
Microbial process	Respiration		150	150	225	225	2				6	5.7	9	Haanstra & Doelman 1984
Microbial process	Respiration		150	150	225	225	2				7.7	2.4	19	Haanstra & Doelman 1984
Microbial process	Respiration		400	400	600	600	2				7.5	3.2	60	Haanstra & Doelman 1984
Microbial process	Respiration		150	150	225	225	2				4.4	12.8	5	Haanstra & Doelman 1984
Microbial process	Respiration		67	67	100	100	3	200			7			Skujins et al. 1986
Microbial process	Urease		390	390	585	585	2	630			7	1.6	2	Doelman & Haanstra 1986
Microbial process	Urease		890	890	1335	1335	2	1110			7.7	2.4	19	Doelman & Haanstra 1986
Microbial process	Urease		350	350	525	525	2	420			7.5	3.2	60	Doelman & Haanstra 1986
Microbial process	Urease	2.5	87	217	130	325	3	260			5.1		17	Tabatabai 1977
Microbial process	Urease	2.5	173	433	260	650	1				6.1		30	Tabatabai 1977
Microbial process	Urease	2.5	173	433	260	650	1				5.8		23	Tabatabai 1977
Microbial process	Urease	2.5	173	433	260	650	1				7.8		30	Tabatabai 1977
Microbial process	Urease	2.5	260	650	390	975	1				6.8		42	Tabatabai 1977
Microbial process	Urease	2.5	173	433	260	650	1				7.4		34	Tabatabai 1977
Microbial process	Nitrate reductase	2.5	43	108	65	163	3	130			6.7		10	Fu & Tabatabai 1989
Microbial process	Nitrate reductase	2.5	130	325	195	488	5		130		7.8		32	Fu & Tabatabai 1989
Microbial process	Nitrate reductase	2.5	87	217	130	325	4			130	7.1		36	Fu & Tabatabai 1989
Microbial process	N-mineralisation	2.5	133	333	200	500	4	500	50	200				Skujins et al. 1986
Microbial process	N-mineralisation	2.5	173	433	260	650	4			260	6.5		26	Liang & Tabatabai 1978
Microbial process	N-mineralisation	2.5	173	433	260	650	4			260	6.6		45	Liang & Tabatabai 1978
Microbial process	N-mineralisation	2.5	260	650	390	975	5		260		7.6		30	Liang & Tabatabai 1978

Scientific name	Toxicity endpoint	ALF	EC10 mg/kg	Final EC10	EC20/30	Final EC30	Category	EC50 mg/kg	NOEC mg/kg	LOEC mg/kg	pH	OM %	Clay %	References
Microbial process	N-mineralisation	2.5	173	433	260	650	4			260	7		34	Liang & Tabatabai 1978
Microbial process	Nitrogenase activity	2.5	67	167	100	250	3	200			7			Skujins et al. 1986
Microbial process	Acid-phosphatase	2.5	520	1300	1300	3250								Juma &Tabatabai 1977
Microbial process	Acid-phosphatase	2.5	520	1300	1300	3250								Juma &Tabatabai 1977
Microbial process	Acid-phosphatase	2.5	520	1300	1300	3250								Juma &Tabatabai 1977
Microbial process	Alkaline phosphatase	2.5	520	1300	1300	3250								Juma &Tabatabai 1977
Microbial process	Alkaline phosphatase	2.5	520	1300	1300	3250								Juma &Tabatabai 1977
Microbial process	Nitrification	2.5	260	650	650	1625			260		6.5		26	Liang & Tabatabai 1978
Microbial process	Nitrification	2.5	260	650	650	1625			260		7.6		30	Liang & Tabatabai 1978
Microbial process	Nitrification	2.5	260	650	650	1625			260		7		34	Liang & Tabatabai 1978
Microbial process	Phosphatase		722	722	1083			20004						Doelman & Haanstra 1989
Microbial process	Phosphatase		857	857	1286			857						Doelman & Haanstra 1989
Microbial process	Phosphatase		280	280	419			4136						Doelman & Haanstra 1989
Microbial process	Phosphatase		2151	2151	3227			2649						Doelman & Haanstra 1989

Appendix F – Raw data for copper

Table 63 Copper toxicity data, including converted values, used to generate Eco-SGVs and associated soil properties

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Polygonum convolvulus	Reproduction	2	200	300	4		6.4	1.7	1.00	11.1	9.2	Kjær & Elmegaard 1996
Fallopia convolvulus	Shoot yield	2	86.3	129.5	3	259	6.7	4.5	2.65	13.8	15.7	Bruus Pedersen et al. 2000
Fallopia convolvulus	Root yield	2	97	145.5	3	291	6.7	4.5	2.65	13.8	15.7	Bruus Pedersen et al. 2000
Avena sativa	Growth	2	200	300	4		5.6	1.6	0.94	12	8.7	De Haan et al. 1985
Avena sativa	Growth	2	200	300	4		5.4	2.4	1.41	40	24.7	De Haan et al. 1985
Avena sativa	Growth	2	200	300	4		5.2	3.2	1.88	58	34.8	De Haan et al. 1985
Avena sativa	Growth	2	200	300	4		5	3.4	2.00	4	6	De Haan et al. 1985
Avena sativa	Growth	2	200	300	4		5.4	6.8	4.00	5	11.3	De Haan et al. 1985
Hordeum vulgare	Root yield	2	58	87	2	137	3.4	8.3	4.88	13	6.7	Rooney et al. 2006
Hordeum vulgare	Root yield	2	16	24	2	36	3.4	3.2	1.88	5	1.9	Rooney et al. 2006
Hordeum vulgare	Root yield	2	85	127.5	2	173	4.2	20.7	12.18	13	15.2	Rooney et al. 2006
Hordeum vulgare	Root yield	2	233	349.5	2	536	4.7	37.3	21.94	24	35.3	Rooney et al. 2006
Hordeum vulgare	Root yield	2	45	67.5	2	95	4.8	2.6	1.53	7	2.4	Rooney et al. 2006
Hordeum vulgare	Root yield	2	14	21	2	40	4.8	0.7	0.41	38	11.2	Rooney et al. 2006
Hordeum vulgare	Root yield	2	83	124.5	2	161	5.1	3.8	2.24	9	4.7	Rooney et al. 2006
Hordeum vulgare	Root yield	2	20	30	2	56	5.2	1.2	0.71	9	2.5	Rooney et al. 2006
Hordeum vulgare	Root yield	2	35	52.5	2	129	5.4	1.4	0.82	51	22.6	Rooney et al. 2006
Hordeum vulgare	Root yield	2	144	216	2	376	6.4	7	4.12	21	23.4	Rooney et al. 2006
Hordeum vulgare	Root yield	2	69	103.5	2	187	6.8	1.6	0.94	15	8.9	Rooney et al. 2006
Hordeum vulgare	Root yield	2	53	79.5	2	359	7.3	2.3	1.35	38	26.2	Rooney et al. 2006
Hordeum vulgare	Root yield	2	77	115.5	2	252	7.4	2	1.18	27	20	Rooney et al. 2006
Hordeum vulgare	Root yield	2	120	180	2	405	7.4	4.2	2.47	46	36.3	Rooney et al. 2006
Hordeum vulgare	Root yield	2	96	144	2	344	7.5	2	1.18	26	20.1	Rooney et al. 2006

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Hordeum vulgare	Root yield	2	111	166.5	2	326	7.5	2.4	1.41	21	14.3	Rooney et al. 2006
Hordeum vulgare	Root yield	2	98	147	2	375	7.5	2.4	1.41	50	23.5	Rooney et al. 2006
Hordeum vulgare	Root yield	2	26	39	2	114	7.5	0.6	0.35	25	16.9	Rooney et al. 2006
Hordeum vulgare		2	114	171	4		5.4	3.3	1.94	23	6.7	ECI 2008
Hordeum vulgare		2	44	66	4		6.5	1.7	1.00	8	8.4	ECI 2008
Hordeum vulgare	Root elongation	2	64	96	2	79	4.39		1.51	66	8.75	Li et al. 2010
Hordeum vulgare	Root elongation	2	31	46.5	2	67	4.76		0.87	46	7.47	Li et al. 2010
Hordeum vulgare	Root elongation	2	175	262.5	2	404	6.67		1.47	25	8.3	Li et al. 2010
Hordeum vulgare	Root elongation	2	110	165	2	277	6.11		1.42	41	19.3	Li et al. 2010
Hordeum vulgare	Root elongation	2	130	195	2	401	6.21		2.46	39	12.8	Li et al. 2010
Hordeum vulgare	Root elongation	2	133	199.5	2	269	6.52		0.99	27	22.3	Li et al. 2010
Hordeum vulgare	Root elongation	2	444	666	2	1073	6.87		4.28	20	22.7	Li et al. 2010
Hordeum vulgare	Root elongation	2	221	331.5	2	589	7.05		2.66	37	22.7	Li et al. 2010
Hordeum vulgare	Root elongation	2	393	589.5	2	1129	7.21		2.17	45	28.8	Li et al. 2010
Hordeum vulgare	Root elongation	2	325	487.5	2	644	5.98		3.03	40	33.6	Li et al. 2010
Lactuca sativa	Shoot biomass	2	292	438.5	3	877	4.9		0.90		17.5	Ginocchio et al. 2006
Lycopersicon esculentum	Shoot yield	2	46	69	2	130	3.4	8.3	4.88	13	6.7	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	6	9	2	22	3.4	3.2	1.88	5	1.9	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	159	238.5	2	427	4.2	20.7	12.18	13	15.2	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	370	555	2	829	4.7	37.3	21.94	24	35.3	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	48	72	2	115	4.8	2.6	1.53	7	2.4	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	29	43.5	2	61	4.8	0.7	0.41	38	11.2	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	89	133.5	2	237	5.1	3.8	2.24	9	4.7	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	23	34.5	2	64	5.2	1.2	0.71	9	2.5	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	179	268.5	2	281	5.4	1.4	0.82	51	22.6	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	598	897	2	851	6.4	7	4.12	21	23.4	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	252	378	2	351	6.8	1.6	0.94	15	8.9	Rooney et al. 2006

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Lycopersicon esculentum	Shoot yield	2	311	466.5	4		7.3	2.3	1.35	38	26.2	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	481	721.5	2	795	7.4	2	1.18	27	20	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	212	318	2	771	7.4	4.2	2.47	46	36.3	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	212	318	2	659	7.5	2	1.18	26	20.1	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	251	376.5	2	444	7.5	2.4	1.41	21	14.3	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	116	174	2	429	7.5	2.4	1.41	50	23.5	Rooney et al. 2006
Lycopersicon esculentum	Shoot yield	2	70	105	2	325	7.5	0.6	0.35	25	16.9	Rooney et al.. 2006
Lycopersicon esculentum		2	106	159	4		5.4	3.3	1.94	23	6.7	ECI 2008
Lycopersicon esculentum		2	71	106.5	4		5	0.3	0.18	9	1.9	ECI 2008
Triticum aestivum	Grain yield	1	1133	1139	1	1147	7.6	1	1.10	12.4	19	Warne et al..2008a
Triticum aestivum	Grain yield	1	132	176	1	286	5.4		0.90	4	3	Warne et al. 2008a
Triticum aestivum	Grain yield	1	731	1561	1	5705	7.3		1.40	66	25	Warne et al. 2008a
Triticum aestivum	Grain yield	1	148	228	1	476	4.9		2.00	23	15	Warne et al. 2008a
Triticum aestivum	Grain yield	1	284	385	1	649	4		5.60	5	10	Warne et al. 2008a
Triticum aestivum	Grain yield	1	130	157	1	212	4.4		1.20	17	30	Warne et al. 2008a
Triticum aestivum	Grain yield	1	209	242	1	310	5		1.80	41	60	Warne et al. 2008a
Triticum aestivum	Grain yield	1	787	1316	1	3170	5.1		3.40	24	20	Warne et al. 2008a
Triticum aestivum	Grain yield	1	586	603	1	632	6.3		1.90	27	24	Warne et al. 2008a
Triticum aestivum	Grain yield	1	622	752	1	1040	6.3		1.80	10	9	Warne et al. 2008a
Triticum aestivum	Grain yield	1	473	768	1	1760	4.8		2.60	6	3	Warne et al. 2008a
Zea mays	Grain yield	2	23	34.5	2	65	5.30		0.87	46	7.47	Guo et al. 2010
Allobophora chlorotica	Cocoon production	2	28	42	2	68	4.8-5.2	4-6		2-4	7	Ma, 1988
Allobophora caliginosa	Cocoon production	2	50	75	5							Martin 1986
Aporrectodea caliginosa	Cocoon production	2	27	40.5	2	51	4.8-5.2	4-6		2-4	7	Ma 1988
Aporrectodea caliginosa	Cocoon production	2	69.8	104.7	2	185.8	7.05	21.6				Khalil et al. 1996a, b
Cognettia sphagnetorum	Fragmentation	2	455	538	1	676	4.1	66		5.1	60.6	Augustsson & Rundgren 1998

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Cognettia sphagnetorum	Fragmentation	2	23	82	1		4.1	66		5.1	60.6	Augustsson & Rundgren 1998
Caenorhabditis elegans	Reproduction	2	23	34	3	68	5.5-8				10-16.5	Huguier et al. 2013
Eisenia andrei	Cocoon production	2	100	150	5		6	10		20	14.5	Kula & Larink 1997
Eisenia andrei	Cocoon production	2	3.2	4.8	5		5.8	3.9		5.1	8.3	Kula & Larink 1997
Eisenia fetida	Cocoon production	2	10	15	5	53.3	6.3	10		20	15.4	Spurgeon et al. 1994
Eisenia fetida	Cocoon production	2	29	43.5	5	716	6.1	10		20	14.8	Spurgeon and Hopkin 1995
Eisenia fetida	Cocoon production	2	10	15	5		6	10		20	14.5	Kula and Larink 1997
Eisenia fetida	Cocoon production	2	10	15	5		5.8	3.9		5.1	8.3	Kula and Larink 1997
Eisenia fetida	Cocoon production	2	34	51	2	210	6.5-7.0	3.9-5.5		13-16	16.6	Scott-Fordsmand et al. 2000b
Eisenia fetida	Cocoon formation	2	103	154.5	3	309	6	10		20	14.5	Owojori et al. 2009
Enchytraeus albidus	Reprod-p1	2	132	198	2	305	6	10		20	14.5	Lock & Janssen (2002)
Enchytraeus albidus	Reproduction	2	71	137	1	251	5.8-6.0	5.5		12-16 %	5.8	Amorim et al. 2005
E. albidus	Reproduction	2	32	48.5	3	97	5.8	4.4		6	11.2	Amorim et al. 2005
E. luxuriosus	Reproduction	2	22	32.5	3	65	6	8		10	45.8	Amorim et al. 2005
E. luxuriosus	Reproduction	2	27	40.5	3	81	5.8	4.4		6	11.2	Amorim et al. 2005
E. luxuriosus	Reproduction	2	16	24	3	48	5.4	4.1		23	68.5	Amorim et al. 2005
E. luxuriosus	Reproduction	2	30	45.5	3	91	6.7	6.5		26	75.8	Amorim et al. 2005
Lumbricus rubellus	Reproduction	2	40	60	5		4.8	5.7		2	7.2	Ma, 1984
Lumbricus rubellus	Reproduction	2	40	60	5		4.8	5.7		2	7.2	Ma, 1984
Plectus acuminatus	Reproduction	2	32	48	5		5.5	10		20	13	Kammenga et al. 1996
Platynothrus peltifer	Reproduction	2	63	94.5	5		5.8	3.9		5.1	8.3	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	161	241.5	2	190	3	8.2		7	5.8	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	84	126	2	211	3.4	8.3		13	6.7	Van Gestel & Doornekamp 1998

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Eisenia fetida	Reproduction	2	120	180	2	708	4.7	37.3		24	35.3	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	86	129	2	171	4.8	2.6		7	2.4	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	88	132	2	296	4.8	0.7		38	11.2	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	67	100.5	2	198	5.1	3.8		9	4.7	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	31	46.5	2	67	5.2	1.2		9	2.5	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	213	319.5	2	329	6.4	7		21	23.4	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	195	292.5	2	230	6.8	1.6		15	8.9	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	279	418.5	2	487	7.3	2.3		38	26.2	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	151	226.5	2	267	7.4	2		27	20	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	346	519	2	407	7.4	4.2		46	36.3	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	148	222	2	309	7.5	2		26	20.1	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	454	681	2	731	7.5	2.4		50	23.5	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	188	282	2	358	5.4	3.3		23	6.7	Van Gestel & Doornekamp, 1998
Eisenia fetida	Reproduction	2	69	103.5	2	149	5				7.88	Van Gestel & Doornekamp 1998
Eisenia fetida	Reproduction	2	223	334.5	2	347	6.45				16.74	Van Gestel & Doornekamp 1998

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Eisenia andrei	Reproduction	2	154	231	5		5				7.88	Van Gestel & Doornekamp 1998
Hypoaspis aculeifer	Reproduction	2	174	261	5		5.8	3.9		5.1	8.3	Krogh & Axelsen 1998
Isotoma viridis	Growth	2	50	75	5		5.8	3.9		5.1	8.3	Rundgren & Van Gestel 1988
Isotoma viridis	Growth	2	400	600	5		6	10		20	14.59	Rundgren & Van Gestel 1988
Folsomia candida	Reproduction	2	200	300	5		6	10		20	14.5	Sandifer & Hopkin 1996
Folsomia candida	Reproduction	2	200	300	5		5	10		20	11.5	Sandifer & Hopkin 1996
Folsomia candida	Reproduction	2	1000	1500	5		4.5	10		20	10	Sandifer & Hopkin 1996
Folsomia candida	Reproduction	2	200	300	5		6	10		20	14.5	Sandifer & Hopkin 1997
Folsomia candida	Reproduction	2	200	300	5		6	10		20	14.5	Sandifer & Hopkin 1997
Folsomia candida	Reproduction	2	63	94.5	2		5.8	3.9		5.1	8.3	Rundgren & Van Gestel 1988
Folsomia candida	Reproduction	2	308	462	2		6	10		20	14.5	Rundgren & Van Gestel 1988
Folsomia fimetaria	Reproduction	2	56	84	2	129	5.5	3.91		5	7.8	Scott-Fordsmand et al. 1997
Folsomia fimetaria	Reproduction	2	310	465	2	865	6.5-7.0	3.9-5.5		13-16	16.6	Scott-Fordsmand et al. 2000a
Folsomia fimetaria	Reproduction	2	707	688	1		6.7	4.5		13.8	15.6	Bruus Pedersen et al. 2001
Folsomia candida	Reproduction	2	190	285	2	260	3.4	8.3		13	6.7	Criel et al. 2008
Folsomia candida	Reproduction	2	10	15	2	43	3.4	3		5	1.9	Criel et al. 2008
Folsomia candida	Reproduction	2	417	625.5	2	952	4.2	20.7		13	15.2	Criel et al. 2008
Folsomia candida	Reproduction	2	1380	2070	2	2200	4.7	37.3		24	35.3	Criel et al. 2008
Folsomia candida	Reproduction	2	50	75	2	166	4.8	2.6		7	2.4	Criel et al. 2008
Folsomia candida	Reproduction	2	51	76.5	2	112	4.8	0.7		38	11.2	Criel et al. 2008
Folsomia candida	Reproduction	2	206	309	2	325	5.2	1.2		9	2.5	Criel et al. 2008
Folsomia candida	Reproduction	2	186	279	2	325	5.4	1.4		51	22.6	Criel et al. 2008

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Folsomia candida	Reproduction	2	618	927	2	1238	6.4	7		21	23.4	Criel et al. 2008
Folsomia candida	Reproduction	2	195	292.5	2	510	6.8	1.6		15	8.9	Criel et al. 2008
Folsomia candida	Reproduction	2	659	988.5	2	862	7.3	2.5		38	26.2	Criel et al. 2008
Folsomia candida	Reproduction	2	80	120	2	434	7.4	2		27	20	Criel et al. 2008
Folsomia candida	Reproduction	2	1186	1779	2	1626	7.4	4.2		46	36.3	Criel et al. 2008
Folsomia candida	Reproduction	2	550	825	2	845	7.5	2		26	20.1	Criel et al. 2008
Folsomia candida	Reproduction	2	200	300	2	640	7.5	2.4		21	14.3	Criel et al. 2008
Folsomia candida	Reproduction	2	683	1024.5	2	1199	7.5	2.4		50	23.5	Criel et al. 2008
Folsomia candida	Reproduction	2	686	1029	2	835	7.5	0.6		25	16.9	Criel et al. 2008
Folsomia candida	Reproduction	2	227	340.5	2	632	5.4	3.3		23	6.7	Criel et al. 2008
Folsomia candida	Reproduction	2	16	24	2	73	4.3	2.2		9	1.2	Criel et al. 2008
Folsomia candida	Reproduction	2	48	72	5		5	2.3		9	1.9	Criel et al. 2008
Folsomia candida	Reproduction	2	38.8	58.2	2	239	6.5	0.3		8	11.6	Criel et al. 2008
Porcello scaber	Juvenile growth	2	351	526.5	2		5				7.88	Rundgren & Van Gestel 1988
Porcello scaber	Juvenile growth	2	2400	3600	5		6.2	5.5		17		Landcare research 2003
Oppia nitens	Reproduction	2	965.3333	1448	3	2896	6	10		20	14.5	Owojori et al. 2012
Microbial processes	N-mineralisation	2	100	150	5		5.9	3.4	1.98	16	13.8	Quraishi & Cornfield 1973
Microbial processes	Nitrification	2	100	150	5		5.9	3.4	1.98	16	13.8	Quraishi & Cornfield 1973
Microbial processes	Nitrification	2	100	150	5		7.3	3.4	1.98	16	16.3	Quraishi & Cornfield 1973
Microbial processes	Denitrification	2	100	150	5		6.75	3.1	1.80	28.1	22.1	Bollag & Barabasz 1979
Microbial processes	Nitrification	2	104	156	2		3.4	8.3	5.20	13	6.7	Smolders & Oorts 2004
Microbial processes		2	27	40.5	2		4.2	20.7	12.90	13	15.2	Smolders & Oorts 2004
Microbial processes	Nitrification	2	1622	2433	2		4.7	37.3	23.30	24	35.3	Smolders & Oorts 2004
Microbial processes	Nitrification	2	60	90	2		4.8	2.6	1.63	7	2.4	Smolders & Oorts 2004
Microbial processes	Nitrification	2	26	39	2		4.8	0.7	0.41	38	11.2	Smolders & Oorts 2004

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Microbial processes	Nitrification	2	114	171	2		5.1	3.8	2.35	9	4.7	Smolders & Oorts 2004
Microbial processes	Nitrification	2	163	244.5	2		5.4	1.4	0.87	51	22.6	Smolders & Oorts 2004
Microbial processes	Nitrification	2	362	543	2		6.4	7	4.40	21	23.4	Smolders & Oorts 2004
Microbial processes	Nitrification	2	93	139.5	2		6.8	1.6	0.98	15	8.9	Smolders & Oorts 2004
Microbial processes	Nitrification	2	396	594	2		7.3	2.3	1.47	38	26.2	Smolders & Oorts 2004
Microbial processes	Nitrification	2	430	645	2		7.4	2	1.26	27	20	Smolders & Oorts 2004
Microbial processes	Nitrification	2	809	1213.5	2		7.4	4.2	2.61	46	36.3	Smolders & Oorts 2004
Microbial processes	Nitrification	2	531	796.5	2		7.5	2	1.27	26	20.1	Smolders & Oorts 2004
Microbial processes	Nitrification	2	310	465	2		7.5	2.4	1.48	21	14.3	Smolders & Oorts 2004
Microbial processes	Nitrification	2	128	192	2		7.5	2.4	1.51	50	23.5	Smolders & Oorts 2004
Microbial processes	Nitrification	2	52	78	2		7.5	0.6	0.38	25	16.9	Smolders & Oorts 2004
Microbial processes	Nitrification	2	127	190.5	5		5.4	3.3	2.06	23	6.7	ECI 2008
Microbial processes	Nitrification	2	65	97.5	5		5	2.3	1.44	9	1.9	ECI 2008
Microbial processes	Nitrification	2	100	150	5		6.5	0.2	0.13	8	8.4	ECI 2008
Microbial processes	Nitrification	2	50	75	5		6.5	0.3	0.19	8	11.6	Smolders & Oorts 2004
Microbial processes	Dehydrogenase activity	2	10	15	5		7.1	1.9	1.10			Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	1200	1800	5		3	8.2	5.12	7	5.8	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	1060	1590	2		3.4	8.3	5.20	13	6.7	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	2509	3763.5	2		4.2	20.7	12.90	13	15.2	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	699	1048.5	2		4.7	37.3	23.30	24	35.3	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	59	88.5	2		4.8	2.6	1.63	7	2.4	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	90	135	2		4.8	0.7	0.41	38	11.2	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	108	162	2		5.1	3.8	2.35	9	4.7	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	57	85.5	2		5.2	1.2	0.76	9	2.5	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	391	586.5	2		5.4	1.4	0.87	51	22.6	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	596	894	2		6.4	7	4.40	21	23.4	Smolders & Oorts 2004

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Microbial processes	Glucose respiration	2	28	42	2		6.8	1.6	0.98	15	8.9	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	102	153	2		7.3	2.3	1.47	38	26.2	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	79	118.5	2		7.4	2	1.26	27	20	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	89	133.5	2		7.4	4.2	2.61	46	36.3	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	23	34.5	2		7.5	2	1.27	26	20.1	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	112	168	2		7.5	2.4	1.48	21	14.3	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	148	222	2		7.5	2.4	1.51	50	23.5	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	48	72	2		7.5	0.6	0.38	25	16.9	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	170	255	5		5.4	3.3	2.06	23	6.7	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	12	18	5		4.3	2.2	1.38	9	1.2	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	25	37.5	5		5	2.3	1.44	9	1.9	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	100	150	5		6.5	0.2	0.13	8	8.4	Smolders & Oorts 2004
Microbial processes	Glucose respiration	2	27	40.5	5		6.5	0.3	0.19	8	11.6	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	2318	3227	1		3	8.2	5.12	7	5.8	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	732	1483	1		3.4	8.3	5.20	13	6.7	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	3629	4167	1		4.2	20.7	1.86	13	15.2	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	321	899	1		4.7	37.3	12.90	24	35.3	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	29	191	1		4.8	2.6	23.30	7	2.4	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	44	317	1		4.8	0.7	1.63	38	11.2	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	69	319	1		5.1	3.8	0.41	9	4.7	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	52	143	1		5.2	1.2	2.35	9	2.5	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	485	884	1		5.4	1.4	0.76	51	22.6	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	13	76	1		6.8	1.6	4.40	15	8.9	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	221	461	1		7.3	2.3	0.98	38	26.2	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	63	188	1		7.5	2	1.26	26	20.1	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	86	260	1		7.5	2.4	2.61	21	14.3	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	51	76.5	5		4.3	2.2	1.48	9	1.2	Smolders & Oorts 2004

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Microbial processes	Maize respiration	2	83	124.5	5		5	2.3	1.51	9	1.9	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	200	300	5		6.5	0.2	0.38	8	8.4	Smolders & Oorts 2004
Microbial processes	Maize respiration	2	100	150	5		6.5	0.3	0.19	8	11.6	Smolders & Oorts 2004
Microbial processes	Nitrification	2	1059	1589	3	3177	5.2		2.58	23	15.31656	Liang & Tababiati 1978
Microbial processes	Nitrification	2	2118	3177	1		7.2		3.74	30	25.17809	Liang & Tababiati 1978
Microbial processes	Nitrification	2	2118	3177	1		6.8		5.45	34	29.48604	Liang & Tababiati 1978
Microbial processes	Denitrification	2	17	25	1		6.2		1.80	28.1	18.72066	Bollag & Barabasz 1979
Microbial processes	N mineralisation	2	211	317	1		5.2		2.58	23	15.31656	Liang &Tababiati 1977
Microbial processes	N mineralisation	2	317	476	2		6.0		2.95	45	29.66156	Liang &Tababiati 1977
Microbial processes	N mineralisation	2	317	476	2		7.2		3.74	30	25.17809	Liang &Tababiati 1977
Microbial processes	Phosphatase	1	438	658	2	438	5.5	5.7	3.31	9	11	
Microbial processes	Phosphatase	1	170	255	2	743	7.9	2.4	1.40	19	16	Doelman & Haanstra 1989
Microbial processes	Phosphatase	1	960	1439	2	2771	7.3	3.2	1.86	60	30	Doelman & Haanstra 1989
Microbial processes	Phosphatase	1	58	87	2	2440	4.6	12.8	7.44	5	52.5	Doelman & Haanstra 1989
Microbial processes	Acid-phosphatase	2	1059	1588	1		7.2		3.74	30	25.17809	Juma & Tabtabai 1977
Microbial processes	Acid-phosphatase	2	1059	1588	1		6.8		5.45	34	29.48604	Juma & Tabtabai 1977
Microbial processes	Acid-phosphatase	2	529	794	3	1588	5.2		2.58	23	15.31656	Juma & Tabtabai 1977
Microbial processes	Alkaline phosphatase	2	1059	1588	1		7.2		3.74	30	25.17809	Juma & Tabtabai 1977
Microbial processes	Alkaline phosphatase	2	1059	1588	1		6.8		5.45	34	29.48604	Juma & Tabtabai 1977
Microbial processes	Respiration	2	202	2	2	1012	4.6		1.40	8	13.1	Saviozzi et al 1997
Microbial processes	Urease	2	33	50	1		5.9		2.19	31	22.7	Bremner & Douglas 1971
Microbial processes	Urease	2	33	50	1		6.7		3.03	31	33	Bremner & Douglas 1971
Microbial processes	Aryl sulphatase	2	1059	1588	1		5.6		2.73	29	19.5	Al-Khafaji & Tabatabai 1979
Microbial processes	Aryl sulphatase	2	1059	1588	1		7.0		3.24	30	23.8	Al-Khafaji & Tabatabai 1979

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Microbial processes	Aryl sulphatase	2	1059	1588	1		5.9		2.91	26	18.6	Al-Khafaji & Tabatabai 1979
Microbial processes	Aryl sulphatase	2	1588	2382	2		6.4		5.32	34	28.1	Al-Khafaji & Tabatabai 1979
Microbial processes	Urease	1	340	510	2	1990	7.9	2.4	1.40	19	16	Doelman & Haanstra 1986
Microbial processes	Urease	1	520	780	2	1080	7.3	3.2	1.86	60	30	Doelman & Haanstra 1986
Microbial processes	Urease	1	210	315	2	1970	4.6	12.8	7.44	5	52.5	Doelman & Haanstra 1986
Microbial processes	Respiration	1	150	400	1		8.2	1.6	0.93	2	1.5	
Microbial processes	Respiration	1	100	150	1		5.5	5.7	3.31	9	11	Doelman & Haanstra 1984
Microbial processes	Respiration	1	400	1000	1		7.9	2.4	1.40	19	16	Doelman & Haanstra 1984
Microbial processes	Respiration	1	8000	12000	2		7.3	3.2	1.86	60	30	Doelman & Haanstra 1984
Microbial processes	Respiration	1	400	1000	1		4.6	12.8	7.44	5	52.5	Doelman & Haanstra 1984
Microbial processes	Glutamic acid decomposition	1	37	55	1		8.2	1.6	0.93	2	1.5	Haanstra & Doelman 1984
Microbial processes	Glutamic acid decomposition	1	55	400	1		7.9	2.4	1.40	19	16	Haanstra & Doelman 1984
Microbial processes	Glutamic acid decomposition	1	55	400	1		7.3	3.2	1.86	60	30	Haanstra & Doelman 1984
Microbial processes	Glutamic acid decomposition	1	400	1000	1		4.6	12.8	7.44	5	52.5	Haanstra & Doelman 1984
Microbial processes	Aryl sulphatase	1	347	520	1	347	5.5	5.7	3.31	9	11	Haanstra & Doelman 1991
Microbial processes	Aryl sulphatase	1	287	430	1	763	7.9	2.4	1.40	19	16	Haanstra & Doelman 1991
Microbial processes	Aryl sulphatase	1	2669	4003	1	4849	7.3	3.2	1.86	60	30	Haanstra & Doelman 1991
Microbial processes	Aryl sulphatase	1	3323	4985	1	6990	4.6	12.8	7.44	5	52.5	Haanstra & Doelman 1991
Microbial processes	SIN	1	2594	2594	1		7.6		1.20	12	10	NEPC 2013b
Microbial processes	SIN	1	34	254	1		5.4		0.90	4	3	NEPC 2013b
Microbial processes	SIN	1	206	208	1		4.5		1.40	16	5	NEPC 2013b
Microbial processes	SIN	1	1271	1451	1		7.3		1.30	66	55	NEPC 2013b

Organism	Endpoint	ALF	EC10	EC30	Category	EC50	pH	OM	0C	clay	CEC	Reference
Microbial processes	SIN	1	175	228	1		4.9		2.00	23	13	NEPC 2013b
Microbial processes	SIN	1	1	5	1		4		5.60	5	11	NEPC 2013b
Microbial processes	SIN	1	47	70	1		4.4		1.20	17	8	NEPC 2013b
Microbial processes	SIN	1	383	502	1		5		1.80	41	16	NEPC 2013b
Microbial processes	SIN	1	887	914	1		5.1		3.40	24	17	NEPC 2013b
Microbial processes	SIN	1	919	932	1		6.3		1.90	27	18	NEPC 2013b
Microbial processes	SIN	1	502	571	1		6.3		1.80	10	10	NEPC 2013b
Microbial processes	SIN	1	141	225	1		4.8		2.60	6	5	NEPC 2013b
Microbial processes	SIR	1	185	345	1		7.6		1.20	12	10	NEPC 2013b
Microbial processes	SIR	1	3	31	1		5.4		0.90	4	3	NEPC 2013b
Microbial processes	SIR	1	326	450	1		4.5		1.40	16	5	NEPC 2013b
Microbial processes	SIR	1	230	496	1		7.3		1.30	66	55	NEPC 2013b
Microbial processes	SIR	1	255	503	1		4.9		2.00	23	13	NEPC 2013b
Microbial processes	SIR	1	48	134	1		4		5.60	5	11	NEPC 2013b
Microbial processes	SIR	1	39	111	1		4.4		1.20	17	8	NEPC 2013b
Microbial processes	SIR	1	222	559	1		5		1.80	41	16	NEPC 2013b
Microbial processes	SIR	1	202	421	1		5.1		3.40	24	17	NEPC 2013b
Microbial processes	SIR	1	26	73	1		6.3		1.90	27	18	NEPC 2013b
Microbial processes	SIR	1	134	259	1		6.3		1.80	10	10	NEPC 2013b
Microbial processes	SIR	1	25	97	1		4.8		2.60	6	5	NEPC 2013b

Appendix G – Raw data for fluoride

Table 64 Fluoride toxicity data, including converted values, used to generate Eco-SGVs

Scientific	Toxicity Endpoint	EC10 (mg NaF/kg)	EC10 (mg F/kg)	EC20/30 (mg NaF/kg)	EC20/30 (mg NaF/kg)	EC50 (mg NaF/kg)	Category	References
Alium sepa	root yield	200	90.47619	400	180.9524	600	3	Jha et al. 2009
Spinacia olerace	shoot yield	240	108.5714	600	271.4286		1	Jha et al. 2008
Triticum aestivum	total yield	40	18.09524	100	45.2381	200	3	Singh et al. 2001
Vicia faba	biomass	20	9.047619	50	22.61905	100	1	Rathore & Agrawal 1989
Sinus alba	root growth		88.2		220.5	441	3	Telesinski et al. 2012
Triticum aestivum	root growth		100.6		251.5	503	3	Telesinski et al. 2012
Microbial Processes	biomass		3000	8841	4000		1	Ropelewska et al. 2016
Microbial Processes	N-fixation, rhizobia			10	4.52381	50	1	Rathore & Agrawal 1989

Appendix H – Raw data for lead

Table 65 Arsenic toxicity data, including converted values, used to generate Eco-SGVs

Scientific name	Toxicity endpoint	ALF	EC10 (mg/kg)	Final EC10	EC20/30 (mg/kg)	Final EC30 (mg/kg)	Category	EC50 (mg/kg)	NOEC (mg/kg)	LOEC (mg/kg)	pH	OM %	TOC %	Clay %	CEC cmole/kg	References
Avena sativa	Root biomass	4.2	100	420	500	2100	4	300	100	500						Khan & Frankland 1984
Triticum aestivum	Root biomass	4.2	500	2100	1000	4200	4	750	500	1000						Khan & Frankland 1984
Triticum aestivum	Shoot growth	4.2	5200	21840	7800	32760	2				7.5	3.3		22		Waegeneers et al. 2004 in LDAI 2008
Triticum aestivum	Shoot growth	4.2	3727	15653	5591	23480	2				7.3	3.7		19		Waegeneers et al. 2004 in LDAI 2008
Triticum aestivum	Shoot growth	4.2	4079	17132	6119	25698	2				6.6	1.6		12		Waegeneers et al. 2004 in LDAI 2008
Raphanus sativus	Root biomass	4.2	100	420	500	2100	4	1800	100	500						Khan & Frankland 1983
Raphanus sativus	Biomass	4.2	100	420	500	2100	4		100	500	6.9	1		20		Zaman & Zereen 1998
Glycine max	Shoot growth	4.2	276	1160	414	1740	3	828.69								Cao et al. 2009b
Latuca sativa	Shoot growth	4.2	1374	5771	2061	8656	1	4,122			5.5		5.66	29	17.6	Stevens et al. 2003
Latuca sativa	Shoot growth	4.2	33	137	49	206	1	98			6.2		0.31	0.3	3.3	Stevens et al. 2003
Latuca sativa	Shoot growth	4.2	364	1529	546	2293	1	1,092			8.5		0.55	4.1	6.4	Stevens et al. 2003
Latuca sativa	Shoot growth	4.2	1065	4472	1597	6707	1	3,194			6.8		0.96	12	9.5	Stevens et al. 2003
Latuca sativa	Shoot growth	4.2	655	2751	983	4127	1	1,965			5.7		2.83	22	16.3	Stevens et al. 2003
Lolium perenne	Dry matter growth	4.2	209	879	314	1319	1	785			4.78		4.06	68.2		Anderson & Basta 2009
Lolium perenne	Dry matter growth	4.2	257	1078	385	1617	1	961			5.49		7.21	101		Anderson & Basta 2009
Lolium perenne	Dry matter growth	4.2	319	1338	478	2008	1	856			6.27		14.3	222		Anderson & Basta 2009
Lolium perenne	Dry matter growth	4.2	660	2772	990	4158	1	2693			7.76		6.57	286		Anderson & Basta 2009
Lolium perenne	Dry matter growth	4.2	899	3777	1349	5666	1	4191			6.06		23.9	418		Anderson & Basta 2009
Lycopersicon esculentum	Shoot yield		6480	6480	9720	9720	2	12600			7		16	16	14.4	Smolders et al. 2015
Lycopersicon esculentum	Shoot yield		>5620	5620	8430	8430	2				6.7		33	30	22.3	Smolders et al. 2015
Lycopersicon esculentum	Shoot yield		420	420	630	630	2	4480			6.6		14	12	8.2	Smolders et al. 2015
Hordeum vulgare	Shoot yield	4.2	50	210	250	1050	1	1250			7.8					Aery & Jagetiya 1997
Hordeum vulgare	Shoot yield		>7020	7020	10530	10530	2				7		16	16	14.4	Smolders et al. 2015
Hordeum vulgare	Shoot yield		5270	5270	7905	7905	2				6.6		14	12	8.2	Smolders et al. 2015
Hordeum vulgare	Shoot yield		>5620	5620	8430	8430	2				6.7		33	30	22.3	Smolders et al. 2015
Pheretima guillelmi	Survival	4.2	2000	8400	3000	12600	5		2000		5.5-6.0		10	20		Zheng and Li 2009
Eisenia fetida	Reproduction	4.2	350	1470	525	2205	2	1270					16	16	14.4	Smolders et al. 2015
Eisenia fetida	Reproduction	4.2	1610	6762	2415	10143	2	3280					33	30	22.3	Smolders et al. 2015
Eisenia fetida	Reproduction	4.2	543	2281	815	3421	3	1629	608	912	6.1					Spurgeon & Hopkin 1995
Eisenia fetida	Reproduction	4.2	647	2716	970	4074	3	1940	1810		6.3					Spurgeon et al. 1994
Eisenia fetida	Reproduction	4.2	331	1390	497	2085	3	993			6.7		2.8		17.6	Davies et al. 2003a

Scientific name	Toxicity endpoint	ALF	EC10 (mg/kg)	Final EC10	EC20/30 (mg/kg)	Final EC30 (mg/kg)	Category	EC50 (mg/kg)	NOEC (mg/kg)	LOEC (mg/kg)	pH	OM %	TOC %	Clay %	CEC cmole/kg	References
Eisenia fetida	Reproduction	4.2	324	1359	486	2039	3	971	400				4	16		Davies et al. 2002
Lumbricus rubellus	Growth	4.2	434	1824	652	2736	3	1303			5.8	5.4				Langdon et al. 2005
Aporrectodea caliginosa	Growth	4.2	403	1691	604	2537	3	1208			5.8	5.4				Langdon et al. 2005
Eisenia andrei	Growth	4.2	947	3977	1421	5966	3	2841			5.8	5.4				Langdon et al. 2005
Dendrobaena rubida	Hatching success	4.2	129	542	194	813	3	387	129	194	4.5					Bengtsson et al. 1986
Dendrobaena rubida	Hatching success	4.2	559	2348	839	3522	5		>559		5.5					Bengtsson et al. 1986
Dendrobaena rubida	Hatching success	4.2	557	2339	836	3509	5		>557		6.5					Bengtsson et al. 1986
Oppia nitens	Reproduction	4.2	559	2349	839	3524	3	1678			6±0.5					Owojori et al., 2012
Folsomia candida	Reproduction		>7020	7020	10530	10530	2	n.s.			7		16 g/kg	16	14.4	Smolders et al. 2015
Folsomia candida	Reproduction		>6410	6410	9615	9615	2	n.s.			6.6		14 g/kg	12	8.2	Smolders et al. 2015
Folsomia candida	Reproduction		1660	1660	2490	2490		n.s.			6.7		33 g/kg	30	22.3	Smolders et al. 2015
Folsomia candida	Reproduction	4.2	1300	5460	1950	8190	2	1900			6.1		2.27		9	Bongers et al. 2004
Folsomia candida	Reproduction	4.2	360	1512	540	2268	2	580			6.1		2.27		9	Bongers et al. 2004
Folsomia candida	Reproduction	4.2	990	4158	1485	6237	3	2970	2000	5000	6					Sandifer & Hopkin 1996
Folsomia candida	Reproduction	4.2	453	1904	680	2856	3	1360	400	2000	5					Sandifer & Hopkin 1996
Folsomia candida	Reproduction	4.2	1053	4424	1580	6636	3	3160	2000	5000	4.5					Sandifer & Hopkin 1996
Folsomia candida	Reproduction	4.2	990	4158	1485	6237	3	2970	2000		6					Sandifer & Hopkin 1997
Folsomia candida	Reproduction	4.2	523	2198	785	3297	3	1570	400	2000	6					Sandifer & Hopkin 1997
Folsomia candida	Reproduction	4.2	2064	8669	3096	13003	5		2064		7.3	3.7		19		Waegeneers et al. 2004 in LDAI 2008
Folsomia candida	Reproduction	4.2	1614	6779	2421	10168	5		1614		6.6	1.6		12		Waegeneers et al. 2004 in LDAI 2008
Folsomia candida	Reproduction	4.2	1138	4780	1707	7169	5		1138		7.5	3.3		22		Waegeneers et al 2004 in LDAI 2008.
Folsomia candida	Reproduction	4.2	260	1091	390	1637	2	1110.4			6.1	1.6		24.8		Bur et al. 2012
Folsomia candida	Reproduction	4.2	1078	4526	1617	6790	2	2573.8			8.2	2		37.2		Bur et al. 2012
Folsomia candida	Reproduction	4.2	6	23	8	35	2	181			4.5	16.5		19.4		Bur et al. 2012
S. curviseta	Reproduction	4.2	642	2696	963	4045	2	3212			6.5			12	20.1	Xu et al. 2009
Paronychiurus kimi	Reproduction	4.2	143	599	214	899	2	428	250	500	6.0 ± 0.5			20		Son et al. 2007
Enchytraeus albidus	Reproduction	4.2	55	231	83	347	2	320			6			20		Lock & Janssen 2002
Microbial Processes	Respiration		1000	1000	1500	1500	2				7	1.6		2	1-2	Doelman & Haanstra 1984
Microbial Processes	Respiration		150	150	225	225	2				6	5.7		9	10-12	Doelman &d Haanstra 1984
Microbial Processes	Respiration		>8000	8000	12000	12000	2				7.7	2.4		19	16	Doelman & Haanstra 1984
Microbial Processes	Respiration		>8000	8000	12000	12000	2				7.5	3.2		60	30	Doelman & Haanstra 1984
Microbial Processes	Respiration		400	400	400	400	2				4.4	12.8		5	50-55	Doelman & Haanstra 1984
Microbial Processes	Respiration	4.2	>8000	33600	12000	50400	2		>8000		7.96		5.43	23.6	21.4	Romero-Freire et al. 2015b
Microbial Processes	Respiration	4.2	3128	13138	4692	19706	2		2000		8.67		0.42	11.8	9.83	Romero-Freire et al. 2015b
Microbial Processes	Respiration	4.2	5951	24994	8927	37491	2		4000		8.79		0.38	7.7	2.94	Romero-Freire et al. 2015b

Scientific name	Toxicity endpoint	ALF	EC10 (mg/kg)	Final EC10	EC20/30 (mg/kg)	Final EC30 (mg/kg)	Category	EC50 (mg/kg)	NOEC (mg/kg)	LOEC (mg/kg)	pH	OM %	TOC %	Clay %	CEC cmole/kg	References
Microbial Processes	Respiration	4.2	90	378	135	567	2		<500		6.74		0.61	19.1	9.91	Romero-Freire et al. 2015b
Microbial Processes	Respiration	4.2	>8000	33600	12000	50400	2		>8000		7.2		8.22	23.8	25.9	Romero-Freire et al. 2015b
Microbial Processes	Respiration	4.2	122	512	183	769	2		<500		5.87		0.49	8.3	3.83	Romero-Freire et al. 2015b
Microbial Processes	Respiration	4.2	45	189	68	284	2		<500		7.03		0.66	54.8	15.5	Romero-Freire et al. 2015b
Microbial Processes	Nitrification rate (PNR)		>7020	7020	10530	10530	2				7		16 g/kg	16	14.4	Smolders et al. 2015
Microbial Processes	Nitrification rate (PNR)		>6410	6410	9615	9615	2				6.6		14 g/kg	12	8.2	Smolders et al. 2015
Microbial Processes	Nitrification rate (PNR)		>5620	5620	8430	8430	2				6.7		33	30	22.3	Smolders et al. 2015
Microbial Processes	Nitrification	4.2	133	559	200	838	2				7.5	3.3		22		Waegeneers et al. 2004 in LDAI 2008
Microbial Processes	Nitrification	4.2	1997	8387	2996	12581	2				7.3	3.7		19		Waegeneers et al. 2004 in LDAI 2008
Microbial Processes	Nitrification	4.2	141	592	212	888	2				6.6	1.6		12		Waegeneers et al. 2004 in LDAI 2008
Microbial Processes	SIN		>7020	7020	10530	10530	2				7		16	16	14.4	Smolders et al. 2015
Microbial Processes	SIN		5620	5620	8430	8430	2				6.6		14	12	8.2	Smolders et al. 2015
Microbial Processes	SIN		>5620	5620	8430	8430	2				6.7		33	30	22.3	Smolders et al. 2015
Microbial Processes	SIR		1740	1740	2610	2610	2				7		16	16	14.4	Smolders et al. 2015
Microbial Processes	SIR		3730	3730	5595	5595	2				6.7		33	30	22.3	Smolders et al. 2015
Microbial Processes	SIR		1160	1160	1740	1740	2				6.6		14	12	8.2	Smolders et al. 2015
Microbial Processes	Denitrification	4.2	500	2100	750	3150	5		500	1000	6.75		1.8	28.1		Bollag&Barabasz 1979
Microbial Processes	Nitrate reductase	4.2	173	725	259	1088	3	518			6.7		2.99	10		Fu & Tabatabai 1989
Microbial Processes	Nitrate reductase	4.2	518	2176	777	3263	5		518		7.8		4.66	32		Fu & Tabatabai 1989
Microbial Processes	Nitrate reductase	4.2	345	1450	518	2176	1				7.1		5.5	36		Fu & Tabatabai 1989
Microbial Processes	Glutamic acid decomposition		55	55	83	83		400			7	1.6		2	1-2	Haanstra & Doelman 1984
Microbial Processes	Glutamic acid decomposition		>1000	1000	1500	1500		>1000			7.7	2.4		19	16	Haanstra & Doelman 1984
Microbial Processes	Glutamic acid decomposition		400	400	600	600	2	1000			7.5	3.2		60	30	Haanstra & Doelman 1984
Microbial Processes	Glutamic acid decomposition		400	400	600	600	2	1000			4.4	12.8		5	50-55	Haanstra & Doelman 1984
Microbial Processes	Urease		860	860	1290	1290	2	1590			7	1.6		2	1-2	Doelman & Haanstra 1986
Microbial Processes	Urease		2440	2440	3660	3660	2	2870			6	5.7		9	10-12	Doelman & Haanstra 1986
Microbial Processes	Urease		6860	6860	10290	10290	2	8130			7.7	2.4		19	16	Doelman & Haanstra 1986
Microbial Processes	Urease		80	80	120	120	2	1340			7.5	3.2		60	30	Doelman & Haanstra 1986
Microbial Processes	Urease		6000	6000	9000	9000	2	7050			4.4	12.8		5	50-55	Doelman & Haanstra 1986
Microbial Processes	Urease	4.2	50	210	315	315	5		50		6.5		2.19	31		Bremner & Douglas 1971
Microbial Processes	Urease	4.2	50	210	315	315	5		50		7.3		3.03	31		Bremner & Douglas 1971
Microbial Processes	Aryl sulphatase		276	276	413	413	2	8785.28			7	1.6		2	1-2	Haanstra & Doelman 1991

Scientific name	Toxicity endpoint	ALF	EC10 (mg/kg)	Final EC10	EC20/30 (mg/kg)	Final EC30 (mg/kg)	Category	EC50 (mg/kg)	NOEC (mg/kg)	LOEC (mg/kg)	pH	OM %	TOC %	Clay %	CEC cmole/kg	References
Microbial Processes	Aryl sulphatase		2652	2652	3978	3978	2	3004.4			6	5.7		9	10-12	Haanstra & Doelman 1991
Microbial Processes	Aryl sulphatase		1635	1635	2452	2452	2	4537.68			7.7	2.4		19	16	Haanstra & Doelman 1991
Microbial Processes	Aryl sulphatase		1906	1906	2859	2859	2	12411.28			7.5	3.2		60	30	Haanstra & Doelman 1991
Microbial Processes	Aryl sulphatase	4.2	5180	21756	7770	32634	2				6.2		2.73	29		Al-Khafaji & Tabatabai 1979
Microbial Processes	Aryl sulphatase	4.2	5180	21756	7770	32634	5		5180		7.6		3.24	30		Al-Khafaji & Tabatabai 1979
Microbial Processes	Aryl sulphatase	4.2	3453	14504	5180	21756	1				6.5		2.91	26		Al-Khafaji & Tabatabai 1979
Microbial Processes	Aryl sulphatase	4.2	5180	21756	7770	32634	2				7		5.32	34		Al-Khafaji & Tabatabai 1979
Microbial Processes	N mineralisation	4.2	691	2901	1036	4351	1				6.5		2.91	26		Liang &Tabatabai 1977
Microbial Processes	N mineralisation	4.2	691	2901	1036	4351	1				6.6		2.95	45		Liang &Tabatabai 1977
Microbial Processes	N mineralisation	4.2	691	2901	1036	4351	1				7.6		3.24	30		Liang &Tabatabai 1977
Microbial Processes	N mineralisation	4.2	1036	4351	1554	6527	2				7		5.32	34		Liang &Tabatabai 1977
Microbial Processes	N mineralisation	4.2	200	840	300	1260	5		200		6.9	2.2	1.31			Chang &Broadbent 1982
Microbial Processes	Nitrification	4.2	6907	29008	10360	43512	1				5.8		2.58	23	12.6	Liang & Tabatabai 1978
Microbial Processes	Nitrification	4.2	10360	43512	15540	65268	2				7.8		3.74	30	19.1	Liang & Tabatabai 1978
Microbial Processes	Nitrification	4.2	10360	43512	15540	65268	2				7.4		5.45	34	21.0	Liang & Tabatabai 1978
Microbial Processes	Acid-phosphatase	4.2	5180	21756	7770	32634	2				7.8		3.74	30	19.1	Juma & Tatatabai 1977
Microbial Processes	Acid-phosphatase	4.2	5180	21756	7770	32634	2				7.4		5.45	34	21.0	Juma & Tatatabai 1977
Microbial Processes	Acid-phosphatase	4.2	3453	14504	5180	21756	1				5.8		2.58	23	12.6	Juma & Tatatabai 1977
Microbial Processes	Alkaline phosphatase	4.2	3453	14504	5180	21756	1				7.8		3.74	30	19.1	Juma & Tatatabai 1977
Microbial Processes	Alkaline phosphatase	4.2	3453	14504	5180	21756	1				7.4		5.45	34	21.0	Juma & Tatatabai 1977
Microbial Processes	Phosphatase		201	201	301	301	2				7	1.6		2	1-2	Doeman & Haanstra 1989
Microbial Processes	Phosphatase		1970	1970	2956	2956	2				7.7	2.4		19	16	Doeman & Haanstra 1989

Appendix I – Raw data for zinc

Table 66 Zinc toxicity data, including converted values, used to generate Eco-SGVs

Location	*Scientific name*	Toxicity endpoint	ALF	EC10 (mg/kg)	EC30 (mg/kg)	Category	EC50 (mg/kg)	pH	OM (%)	TOC (%)	Clay (%)	CEC (cmol/kg)	Reference
Australia	*A. hypogaea*		1	16	24	1		4.5				4.9	NEPC 2013b
Europe	*Allium cepa*	Yield plant	3	200	300	5		8.3	0.5		24	17.0	Dang et al. 1990
Australia	*Arachis hypogaea*		1	227	341	1		5.0				16.5	NEPC 2013b
Europe	*Avena sativa*	Grain	3	100	150	5		5.6	2		12	9.2	De Haan et al. 1985
Europe	*Avena sativa*	Grain	3	200	300	5		5.4	2		40	24.0	De Haan et al. 1985
Europe	*Avena sativa*	Grain	3	200	300	5		5.0	3		4	5.5	De Haan et al. 1985
Europe	*Avena sativa*	Grain	3	400	600	5		5.4	7		5	11.5	De Haan et al. 1985
Europe	*Beta vulgaris*	Yield plant	3	300	450	5		7.5	_		_		Boawn & Rasmussen 1971
Australia	*Brassica napus*		1	179	268	1		6.3				10.3	NEPC 2013b
Australia	*Brassica napus*		1	139	209	1		5.4				3.2	NEPC 2013b
Australia	*Brassica napus*		1	52	78	1		4.8				5.0	NEPC 2013b
Australia	*Brassica napus*		1	145	217	1		4.9				13.0	NEPC 2013b
Europe	*Brassica rapa*	Biomass (fw)	3	71	107	2		6.0		4.7	8.04	8.9	Rombke et al. 2006
Europe	*Brassica rapa*	Biomass (fw)	3	31	47	2		4.9		2.34	29.7	14.1	Rombke et al. 2006
Europe	*Brassica rapa*	Biomass (fw)	3	85	128	2		5.5		0.94	3.82	2.0	Rombke et al. 2006
Europe	*Brassica rapa*	Biomass (fw)	3	169	254	2		5.2		2.64	24.9	13.2	Rombke et al. 2006
Europe	*Brassica rapa*	Biomass (fw)	3	419	629	2		5.8		3.37	25.9	11.8	Rombke et al. 2006
Europe	*Brassica rapa*	Biomass (fw)	3	923	1385	2		7.4		2.22	22.5	19.8	Rombke et al. 2006
Europe	*Brassica rapa*	Biomass (fw)	3	20	30	2		6.6		1.63	15	13.8	Rombke et al. 2006
Europe	*Brassica rapa*	Biomass (fw)	3	70	105	2		6.1		2.7	6.84	7.9	Rombke et al. 2006
Australia	*Gossypium sp*		1	2128	3191	1		7.3				61.0	NEPC 2013b
Australia	*Hordeum vulgare*	Shoot	1	56	85	1		7.6				10.0	NEPC 2013b
Australia	*Hordeum vulgare*	Root	1	490	736	1		6.3				17.7	NEPC 2013b
Australia	*Hordeum vulgare*	Yield plant	1	487	730	1		6.3				10.3	NEPC 2013b
Europe	*Hordeum vulgare*		3	67	100	1		5.6	8		13	17.6	Luo & Rimmer 1995
Europe	*Hordeum vulgare*		3	215	323	5		7.8	1		-		Aery & Jagetiya 1997
Europe	*Hordeum vulgare*		3	100	150	5		7.5	_		_		Boawn & Rasmussen 1971
Europe	*Lactuca sativa*	Yield plant	3	400	600	5		7.5	_		_		Boawn & Rasmussen 1971
Europe	*Lolium perenne*	Dry matter growth	3	237	356	1		4.8	0.697	0.41	6.82	4.1	Anderson et al. 2009
Europe	*Lolium perenne*	Dry matter growth	3	236	817	1		5.5	1.224	0.72	10.1	4.2	Anderson et al. 2009
Europe	*Lolium perenne*	Dry matter growth	3	688	1032	1		6.3	2.431	1.43	22.2	14.2	Anderson et al. 2009
Europe	*Lolium perenne*	Dry matter growth	3	398	597	1		7.8	1.122	0.66	28.6	27.9	Anderson et al. 2009
Europe	*Lolium perenne*	Dry matter growth	3	907	1361	1		6.1	4.063	2.39	41.8	25.7	Anderson et al. 2009
Europe	*Lycopersicon esculentum*	Yield plant	3	400	600	5		7.5	_		_		Boawn & Rasmussen 1971
Europe	*Medicago sativa*	Yield plant	3	300	450	5		7.5	_		_		Boawn & Rasmussen 1971
Australia	*Panicum milaceum*		1	419	629	1		5.0				16.5	NEPC 2013b
Europe	*Pisum sativum*	Yield plant	3	400	600	5		7.5	_		_		Boawn & Rasmussen 1971
Australia	*Saccharum*		1	780	1170	1		4.5				4.9	NEPC 2013b

Location	*Scientific name*	Toxicity endpoint	ALF	EC10 (mg/kg)	EC30 (mg/kg)	Category	EC50 (mg/kg)	pH	OM (%)	TOC (%)	Clay (%)	CEC (cmol/kg)	Reference
Europe	*Sorghum bicolor*	Yield plant	3	100	150	5		7.5	_		_		Boawn & Rasmussen 1971
Europe	*Sorghum bicolor*	Yield plant	3	200	300	5		7.5	_		_		Boawn & Rasmussen, 1971
Australia	*Sorghum spp*		1	1661	2491	1		7.3				61.0	NEPC 2013b
Europe	*Spinacea oleracea*	Yield plant	3	200	300	5		7.5	_		_		Boawn & Rasmussen, 1971
Europe	*Trifolium pratense*	Root, stem	3	113	170	5		6.2	10		20	26.4	Van der Hoeven & Henzen 1994a, 1994c in EC 2008
Europe	*Trifolium pratense*	Root	3	84	126	5		6.0	10		20`	26.4	Van der Hoeven & Henzen 1994a, 1994c in EC 2008
Europe	*Trifolium pratense*	Root, shoot	3	32	48	5		5.0	5		13?	12.6	Van der Hoeven & Henzen 1994a, 1994c in EC 2008
Europe	*Trifolium pratense*	Root, shoot	3	32	48	5		5.3	2		2	3.5	Van der Hoeven & Henzen 1994c in EC 2008
Europe	*Trifolium pratense*	Root, shoot	3	32	48	5		5.3	2		2	3.5	Hooftman & Henzen 1996 in EC 2008
Europe	*Trifolium pratense*	Root, shoot	3	32	48	5		5.3	2		2	3.5	Hooftman & Henzen 1996 in EC2008
Europe	*Trigonella poenum-*	Yield plant	3	200	300	5		8.3	0.5		24	17.0	Dang et al. 1990
Australia	*Triticum aestivum*	Grain yield	1	4764	7147	1		7.6				10.0	NEPC 2013b
Australia	*Triticum aestivum*	Grain yield	1	91	137	1		5.4				3.2	NEPC 2013b
Australia	*Triticum aestivum*	Grain yield	1	2351	3527	1		7.3				61.0	NEPC 2013b
Australia	*Triticum aestivum*	Grain yield	1	429	643	1		4.9				13.0	NEPC 2013b
Australia	*Triticum aestivum*	Grain yield	1	255	383	1		4.0				11.6	NEPC 2013b
Australia	*Triticum aestivum*	Grain yield	1	374	560	1		4.4				7.8	NEPC 2013b
Australia	*Triticum aestivum*	Grain yield	1	262	394	1		5.0				16.5	NEPC 2013b
Australia	*Triticum aestivum*	Grain yield	1	1313	1969	1		5.1				17.4	NEPC 2013b
Australia	*Triticum aestivum*	Grain yield	1	1217	1825	1		6.3				17.7	NEPC 2013b
Australia	*Triticum aestivum*	Grain yield	1	689	1033	1		6.3				10.3	NEPC 2013b
Australia	*Triticum aestivum*	Grain yield	1	102	153	1		4.8				5.0	NEPC 2013b
Europe	*Triticum vulgare*	Yield plant	3	200	300	5		7.5	_		_		Boawn & Rasmussen 1971
Australia	*Tritosecale*		1	310	465	1		4.0				11.6	NEPC 2013b
Europe	*Vicia sativa*	Root	3	32	48	5		5.0	5?		13?	12.6	Van der Hoeven & Henzen 1994b in EC 2008
Europe	*Vigna mungo*	Root, stem	3	155	233	5		6.2	_		_		Kalyanaraman & Sivagurunathan 1993
Europe	*Zea mays*	Shoot	3	83	125	5		4.9	3		16	11.6	MacLean 1974
Europe	*Zea mays*	Yield plant	3	300	450	5		7.5	_		_		Boawn & Rasmussen 1971
Australia	*Zea mays*		1	501	751	1		5.0				16.5	NEPC 2013b
Europe	*Zea mays ?*	Yield plant	3	200	300	5		7.5	_		_		Boawn & Rasmussen, 1971
Europe	*A. caliginosa*	Reproduction	3	104	156	2		6.4	2.35		9.7	9.2	Spurgeon et al. 2000
Europe	*Aporrectodea caliginosa*	Cocoon production	3	568	852	2		7.1	22		_		Khalil et al. 1996
Europe	*Caenorhabditis elegans*		3	118	177	2		5.7	5.1		10	7.2	Boyd & Williams 2003
Europe	*Caenorhabditis elegans*		3	383	575	2		7.8	5.1		8	28.4	Boyd & Williams 2003
Europe	*Caenorhabditis elegans*		3	112	168	2		6.1	1.4		2	2.4	Boyd & Williams 2003
Europe	*Enchytraeus albidus*		3	132	198	2		6.0	10		20	15.0	Lock & Janssen 2001
Europe	*Enchytraeus albidus*		3	36	54	2		6.3	1.5		17	11.5	Lock & Janssen 2001
Europe	*Enchytraeus albidus*	Survival	3	610	915	2		6.0	10		20	15.0	Lock & Janssen 2002
Europe	*Enchytraeus albidus*	Reproduction (P)	3	262	393	2	345	6.0	10		20	15.0	Lock & Janssen 2002
Europe	*Enchytraeus albidus*	Reproduction (F1)	3	178	267	2	211	6.0	10		20	15.0	Lock & Janssen 2002
Europe	*Enchytraeus albidus*	Reproduction (F1)	3	132	198	2	267	6.0	10		20	15.0	Lock & Janssen 2002

Location	*Scientific name*	Toxicity endpoint	ALF	EC10 (mg/kg)	EC30 (mg/kg)	Category	EC50 (mg/kg)	pH	OM (%)	TOC (%)	Clay (%)	CEC (cmol/kg)	Reference
Europe	*Eisenia andrei*	Reproduction	3	1110	1665	2	1731	6.0		4.7	8.04	8.9	Rombke et al. 2006
Europe	*Eisenia andrei*	Reproduction	3	1106	1659	2	1361	4.9		2.34	29.7	14.1	Rombke et al. 2006
Europe	*Eisenia andrei*	Reproduction	3	118	177	2	422	3.8		1.54	5.1	3.3	Rombke et al. 2006
Europe	*Eisenia andrei*	Reproduction	3	527	791	2	864	5.5		0.94	3.82	2.0	Rombke et al. 2006
Europe	*Eisenia andrei*	Reproduction	3	1090	1635	2	1439	5.2		2.64	24.9	13.2	Rombke et al. 2006
Europe	*Eisenia andrei*	Reproduction	3	773	1160	2	1903	5.8		3.37	25.9	11.8	Rombke et al. 2006
Europe	*Eisenia andrei*	Reproduction	3	427	641	2	1297	7.4		2.22	22.5	19.8	Rombke et al. 2006
Europe	*Eisenia andrei*	Reproduction	3	1289	1934	2	1,804	6.6		1.63	15	13.8	Rombke et al. 2006
Europe	*Eisenia andrei*	Reproduction	3	478	717	2	1083	6.1		2.7	6.84	7.9	Rombke et al. 2006
Europe	*Eisenia andrei*	Cocoon production	3	320	480	5		6.0	10		20	25.6	Van Gestel et al. 1993
Europe	*Eisenia fetida*	Cocoon production	3	122	183	2		6.4	2.35		9.7	9.2	Spurgeon et al. 2000
Europe	*Eisenia fetida*	Cocoon production	3	350	525	2		6.0	10		20	25.6	Spurgeon et al. 1997
Europe	*Eisenia fetida*	Cocoon production	3	350	525	2		6.0	10		20	25.6	Spurgeon et al. 1997
Europe	*Eisenia fetida*	Cocoon production	3	237	356	2		6.1	10		20	26.0	Spurgeon & Hopkin, 1995
Europe	*Eisenia fetida*	Cocoon production	3	199	299	2		6.3	10		20	26.8	Spurgeon et al. 1994
Europe	*Eisenia fetida*	Cocoon production	3	97	146	2		6.0	5		20	18.5	Spurgeon & Hopkin 1996b
Europe	*Eisenia fetida*	Cocoon production	3	553	830	2		6.0	10		20	25.6	Spurgeon & Hopkin 1996b
Europe	*Eisenia fetida*	Cocoon production	3	484	726	2		6.0	15		20	32.8	Spurgeon & Hopkin 1996b
Europe	*Eisenia fetida*	Cocoon production	3	85	128	2		5.0	5		20	16.1	Spurgeon & Hopkin 1996b
Europe	*Eisenia fetida*	Cocoon production	3	183	275	2		5.0	10		20	21.8	Spurgeon & Hopkin 1996b
Europe	*Eisenia fetida*	Cocoon production	3	414	621	2		5.0	15		20	27.5	Spurgeon & Hopkin 1996b
Europe	*Eisenia fetida*	Cocoon production	3	115	173	2		4.0	5		20	13.7	Spurgeon & Hopkin 1996b
Europe	*Eisenia fetida*	Cocoon production	3	161	242	2		4.0	10		20	17.9	Spurgeon & Hopkin 1996b
Europe	*Eisenia fetida*	Cocoon production	3	223	335	2		4.0	15		20	22.2	Spurgeon & Hopkin 1996b
Europe	*Eisenia fetida*	Cocoon production	3	130	195	2	250	3.0	9		7	5.8	Lock et al. 2003 in EC 2008
Europe	*Eisenia fetida*	Cocoon production	3	96	144	2	120	3.4	3		5	1.9	Lock et al. 2003 in EC 2008
Europe	*Eisenia fetida*	Cocoon production	3	1150	1725	2	1820	4.7	40		24	35.3	Lock et al. 2003 in EC 2008
Europe	*Eisenia fetida*	Cocoon production	3	503	755	2	649	4.8	1		38	11.2	Lock et al. 2003 in EC 2008
Europe	*Eisenia fetida*	Cocoon production	3	243	365	2	381	5.1	4		9	4.7	Lock et al. 2003 in EC 2008
Europe	*Eisenia fetida*	Cocoon production	3	1040	1560	2	1310	5.7	6		_		Lock et al. 2003 in EC 2008
Europe	*Eisenia fetida*	Cocoon production	3	629	944	2	1060	6.4	7		21		Lock et al. 2003 in EC 2008
Europe	*Eisenia fetida*	Cocoon production	3	486	729	2	915	4.8	13		_	15.2	Lock et al. 2003 in EC 2008
Europe	*Eisenia fetida*	Cocoon production	3	747	1121	2	1520	5.2	17		_		Lock et al. 2003 in EC 2008
Europe	*Eisenia fetida*	Cocoon production	3	79	119	2	275	6.8	2		15	8.9	Lock et al. 2003 in EC 2008
Europe	*Eisenia fetida*	Cocoon production	3	122	183	2	577	7.5	2		26	20.1	Lock et al. 2003 in EC 2008
Europe	*Eisenia fetida*	Cocoon production	3	346	519	2	531	7.5	1		25	16.9	Lock et al. 2003 in EC 2008
Europe	*Lumbricus rubellus*	Reproduction	3	160	241	3		6.4	2.35		9.7	9.2	Spurgeon et al. 2000
Europe	*Lumbricus terrestis*	Reproduction	3	299	448	3		6.4	2.35		9.7	9.2	Spurgeon et al. 2000
Europe	*Lobella sokamensis*	Survival -juvenile	3	200	300	5	163	6.0					An et al. 2013
Europe	*Lumbricus rubellus*	Reproduction	3	110	164	2	53	4.9	3.4		1.7	5.3	Ma & Bonten 2011
Europe	*Lumbricus rubellus*	Reproduction	3	301	451	2	178	7.3	3.5		17	17.8	Ma & Bonten 2011

Location	*Scientific name*	Toxicity endpoint	ALF	EC10 (mg/kg)	EC30 (mg/kg)	Category	EC50 (mg/kg)	pH	OM (%)	TOC (%)	Clay (%)	CEC (cmol/kg)	Reference
Europe	*Lumbricus rubellus*	Reproduction	3	217	326	2		5.6	3.4		1.7	5.4	Ma & Bonten 2011
Europe	*Lumbricus rubellus*	Reproduction	3	110	165	2		4.4	3.4		1.7	4.1	Ma & Bonten 2011
Europe	*Nematode community*	No of taxa	3	320	480							5.1	Smit et al. 2002
Europe	*Folsomia candida*	Reproduction	3	123	185	2		6.0	10		20	15.0	Lock & Janssen 2001
Europe	*Folsomia candida*	Reproduction	3	316	474	2		6.3	1.5		17	11.5	Lock & Janssen 2001
Europe	*Folsomia candida*	Reproduction	3	15	23	2		4.5	4.8		1	10.1	Lock & Janssen 2001
Europe	*Folsomia candida*	Reproduction	3	969	1454	2	1843	6.0		4.7	8.04	8.9	Rombke et al. 2006
Europe	*Folsomia candida*	Reproduction	3	106	159	2	765	4.9		2.34	29.7	14.1	Rombke et al. 2006
Europe	*Folsomia candida*	Reproduction	3	256	384	2	394	3.8		1.54	5.1	3.3	Rombke et al. 2006
Europe	*Folsomia candida*	Reproduction	3	316	474	2	566	3.1		5.09	4.67	5.0	Rombke et al. 2006
Europe	*Folsomia candida*	Reproduction	3	1058	1587	2	1274	5.5		0.94	3.82	2.0	Rombke et al. 2006
Europe	*Folsomia candida*	Reproduction	3	236	354	2	821	5.2		2.64	24.9	13.2	Rombke et al. 2006
Europe	*Folsomia candida*	Reproduction	3	119	179	2	1189	5.8		3.37	25.9	11.8	Rombke et al. 2006
Europe	*Folsomia candida*	Reproduction	3	840	1260	2	2065	7.4		2.22	22.5	19.8	Rombke et al. 2006
Europe	*Folsomia candida*	Reproduction	3	1181	1772	2	1593	6.6		1.63	15	13.8	Rombke et al. 2006
Europe	*Folsomia candida*	Reproduction	3	1190	1785	2	1755	6.1		2.7	6.84	7.9	Rombke et al. 2006
Europe	*Folsomia candida*	Reproduction	3	267	401	2		6.0	10		20	25.6	Smit & Van Gestel 1998
Europe	*Folsomia candida*	Reproduction	3	113	170	2		6.0	2		2	4.0	Smit & Van Gestel 1998
Europe	*Folsomia candida*	Reproduction	3	334	501	2		6.0	2		2	4.0	Smit & Van Gestel 1998
Europe	*Folsomia candida*	Reproduction	3	620	930	5		6.0	10		20	25.6	Sandifer & Hopkin 1996
Europe	*Folsomia candida*	Reproduction	3	300	450	5		5.0	10		20	21.8	Sandifer & Hopkin 1996
Europe	*Folsomia candida*	Reproduction	3	300	450	5		4.5	10		20	19.9	Sandifer & Hopkin 1996
Europe	*Folsomia candida*	Reproduction	3	300	450	5		6.0	10		20	25.6	Sandifer & Hopkin 1997
Europe	*Folsomia candida*	Reproduction	3	30	45	2	64	3.4	3		5	1.9	Lock et al. 2003 in EC 2008
Europe	*Folsomia candida*	Reproduction	3	520	780	2	1390	4.7	40		24	35.5	Lock et al. 2003 in EC 2008
Europe	*Folsomia candida*	Reproduction	3	88	132	2	395	4.8	13		_	15.2	Lock et al. 2003 in EC 2008
Europe	*Folsomia candida*	Reproduction	3	63	95	2	248	4.8	1		38	11.2	Lock et al. 2003 in EC 2008
Europe	*Folsomia candida*	Reproduction	3	303	455	2	1440	5.2	17		_		Lock et al. 2003 in EC 2008
Europe	*Folsomia candida*	Reproduction	3	209	314	2	682	5.4	1		51	22.6	Lock et al. 2003 in EC 2008
Europe	*Folsomia candida*	Reproduction	3	89	134	2	586	5.7	6		_		Lock et al. 2003 in EC 2008
Europe	*Folsomia candida*	Reproduction	3	588	882	2	903	7.4	2		27	20.0	Lock et al. 2003 in EC 2008
Europe	*Folsomia candida*	Reproduction	3	1210	1815	2	1500	7.4	4		46	36.3	Lock et al. 2003 in EC 2008
Europe	*Folsomia candida*	Reproduction	3	139	209	2	593	7.5	1		25	16.9	Lock et al. 2003 in EC 2008
Europe	*Folsomia candida*	Reproduction	3	399	599	5		6.0	10		20	25.6	Van Gestel & Hensbergen, 1997
Europe	Microbial process	Acid-phosphatase	3	1089	1634	1		7.2			3.74		Juma &Tabtabai 1977
Europe	Microbial process	Acid-phosphatase	3	1089	1634	1		6.8			5.45		Juma &Tabtabai 1977
Europe	Microbial process	Acid-phosphatase	3	1089	1634	1		5.2			2.58		Juma &Tabtabai 1977
Europe	Microbial process	Alkaline phosphatase	3	545	817	3		7.2			3.74		Juma &Tabtabai 1977
Europe	Microbial process	Alkaline phosphatase	3	1089	1634	1		6.8			5.45		Juma &Tabtabai 1977
Europe	Microbial process	Aryl sulphatase	3	1089	1634	1		5.6			2.73		Al-Khafaji & Tabatabai 1979
Europe	Microbial process	Aryl sulphatase	3	1089	1634	1		7.0			3.24		Al-Khafaji & Tabatabai 1979

Location	*Scientific name*	Toxicity endpoint	ALF	EC10 (mg/kg)	EC30 (mg/kg)	Category	EC50 (mg/kg)	pH	OM (%)	TOC (%)	Clay (%)	CEC (cmol/kg)	Reference
Europe	Microbial process	Aryl sulphatase	3	1089	1634	1		5.9			2.91		Al-Khafaji & Tabatabai 1979
Europe	Microbial process	Aryl sulphatase	3	1634	2451	2		6.4			5.32		Al-Khafaji & Tabatabai 1979
Europe	Microbial process	Aryl sulphatase	1	313	470	2		6.4	1.6		0.93		Haanstra & Doelman 1991
Europe	Microbial process	Aryl sulphatase	1	804	1206	2		5.4	5.7		3.3		Haanstra & Doelman 1991
Europe	Microbial process	Aryl sulphatase	1	2720	4080	2		7.1	2.4		1.4		Haanstra & Doelman 1991
Europe	Microbial process	Aryl sulphatase	1	1020	1530	2		6.9	3.2		1.9		Haanstra & Doelman 1991
Europe	Microbial process	Aryl sulphatase	1	7976	11 965	2		3.9	12.8		7.4		Haanstra & Doelman 1991
Europe	Microbial process	ATP	3	124	186	2		7.2	4.4				Frostegaard et al 1993
Europe	Microbial process	Denitrification	3	33	50	1		6.2			1.8		Bollag & Barabasz 1979
Europe	Microbial process	Glucose	3	300	450	5		6.7	2		4[e]		Ohya et al. 1985
Europe	Microbial process	Glucose	3	80	120	5		5.7	1		14		Stadelmann & Santschi-Fuhrimann 1987
Europe	Microbial process	Glucose	3	256	384	2	731	3.0	9		7		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	33	50	2	139	3.4	3		5		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	780	1170	2	3569	4.8	13		-		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	70	105	2	1018	4.8	1		38		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	400	400	5		5.1	4		9		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	1300	1300	5		5.2	17				Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	600	600	5		5.4	1		51		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	227	341	2	6936	5.7	6				Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	653	980	2	1643	6.4	7		21		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	111	167	2	392	6.8	2		15		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	211	317	2	568	7.4	2		27		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	189	284	2	946	7.4	4		46		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	179	269	2	517	7.5	2		26		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glucose	3	95	143	2	355	7.5	1		25		Smolders et al. 2003 in EC 2008
Europe	Microbial process	Glutamic acid decomposition	1	1000	1500	2		7.1	2.4		1.395349		Haanstra & Doelman 1984
Europe	Microbial process	Glutamic acid decomposition	1	55	400	1		6.9	3.2		1.860465		Haanstra & Doelman 1984
Europe	Microbial process	Glutamic acid decomposition	1	400	1000	1		3.9	12.8		7.44186		Haanstra & Doelman 1984
Europe	Microbial process	N mineralisation	3	218	327	1		5.2			2.58		Liang &Tababiati 1977
Europe	Microbial process	N mineralisation	3	218	327	1		6.0			2.95		Liang &Tababiati 1977
Europe	Microbial process	N mineralisation	3	218	327	1		7.2			3.74		Liang &Tababiati 1977
Europe	Microbial process	N mineralisation	3	218	327	1		6.8			5.45		Liang &Tababiati 1977
Europe	Microbial process	Nitrate reductase	3	55	82	3		6.1			2.99		Fu &Tabtabatabai 1978
Europe	Microbial process	Nitrate reductase	3	109	164	1		6.5			5.5		Fu &Tabtabatabai 1978
Europe	Microbial process	Nitrification	3	100	100	5		6.2	2		8		Wilson 1977
Europe	Microbial process	Nitrification	3	50	50	5		5.1	1		2		Wilson 1977
Europe	Microbial process	Nitrification	3	100	150	5		5.5	2		28		Wilson 1977
Europe	Microbial process	Nitrification	3	506	759	2	944	4.7	40		24		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	517	776	2	852	4.8	13		-		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	77	116	2	189	4.8	1		38		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	51	77	2	224	5.1	4		9		Smolders et al. 2003

Location	*Scientific name*	Toxicity endpoint	ALF	EC10 (mg/kg)	EC30 (mg/kg)	Category	EC50 (mg/kg)	pH	OM (%)	TOC (%)	Clay (%)	CEC (cmol/kg)	Reference
Europe	Microbial process	Nitrification	3	436	654	2	1046	5.2	17		_		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	43	65	2	199	5.4	1		51		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	206	309	2	409	5.7	6		_		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	241	362	2	464	6.4	7		21		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	113	170	2	267	6.8	2		15		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	336	504	2	710	7.4	2		27		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	542	813	2	748	7.4	4		46		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	262	393	2	513	7.5	2		26		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	87	131	2	275	7.1	1		25		Smolders et al. 2003
Europe	Microbial process	Nitrification	3	1059	1589	3		5.2			2.58		Liang &Tababiati 1978
Europe	Microbial process	Nitrification	3	2118	3177	1		7.2			3.74		Liang &Tababiati 1978
Europe	Microbial process	Nitrification	3	2118	3177	1		6.8			5.45		Liang &Tababiati 1978
Europe	Microbial process	N-mineralisation	3	233	700	4.00		3.4	8		10e		Necker & Kunze 1986
Europe	Microbial process	Phosphatase	3	508	762	2		4.7	_		_		Svenson 1986
Europe	Microbial process	Phosphatase	1	570	855	2		5.4	5.7		3.313953		Doelman & Haanstra 1989
Europe	Microbial process	Phosphatase	1	300	450	2		7.1	2.4		1.395349		Doelman & Haanstra 1989
Europe	Microbial process	Phosphatase	1	36	54	2		6.9	3.2		1.860465		Doelman & Haanstra 1989
Europe	Microbial process	Phytase	3	590	885	2		4.7					Svenson 1986
Europe	Microbial process	Py-phosphatase	3	1640	2460	2		4.6					Stott et al. 1985
Europe	Microbial process	Py-phosphatase	3	1640	2460	2		6.2					Stott et al. 1985
Europe	Microbial process	Py-phosphatase	3	1640	2460	2		7.4					Stott et al. 1985
Europe	Microbial process	Respiration	3	110	165	5		6.7	3		27		Lighthart et al. 1983
Europe	Microbial process	Respiration	3	327	491	5		6.2	64		-		Lighthart et al. 1983
Europe	Microbial process	Respiration	3	165	248	5		7.0	6		51		Lighthart et al. 1983
Europe	Microbial process	Respiration	3	110	165	5		7.2	2		21		Lighthart et al. 1983
Europe	Microbial process	Respiration	3	17	26	5		8.2	5		11		Lighthart et al. 1983
Europe	Microbial process	Respiration	3	472	708	2		4.6			1.4		Saviozzi et al 1997
Europe	Microbial process	Respiration	1	150	400	1		6.4	1.6		0.930233		Doelman & Haanstra 1984
Europe	Microbial process	Respiration	1	150	400	1		5.4	5.7		3.313953		Doelman & Haanstra 1984
Europe	Microbial process	Respiration	1	1000	3000	1		6.9	3.2		1.860465		Doelman & Haanstra 1984
Europe	Microbial process	Respiration	1	1000	3000	1		3.9	12.8		7.44186		Doelman & Haanstra 1984
Australia	Microbial process	SIN	1	63	95	2		4.5					NEPC 2013b
Australia	Microbial process	SIN	1	1181	1772	2		7.3					NEPC 2013b
Australia	Microbial process	SIN	1	346	519	2		4.9					NEPC 2013b
Australia	Microbial process	SIN	1	10	15	2		4.0					NEPC 2013b
Australia	Microbial process	SIN	1	70	105	2		4.4					NEPC 2013b
Australia	Microbial process	SIN	1	270	405	2		5.0					NEPC 2013b
Australia	Microbial process	SIN	1	901	1352	2		5.1					NEPC 2013b
Australia	Microbial process	SIN	1	919	1379	2		6.3					NEPC 2013b
Australia	Microbial process	SIN	1	462	693	2		6.3					NEPC 2013b
Australia	Microbial process	SIN	1	188	282	2		4.8					NEPC 2013b

Location	*Scientific name*	Toxicity endpoint	ALF	EC10 (mg/kg)	EC30 (mg/kg)	Category	EC50 (mg/kg)	pH	OM (%)	TOC (%)	Clay (%)	CEC (cmol/kg)	Reference
Australia	Microbial process	SIN	1	7538	11 307	2		7.6					NEPC 2013b
Australia	Microbial process	SIN	1	209	314	2		5.4					NEPC 2013b
Australia	Microbial process	SIR	1	369	554	2		4.5					NEPC 2013b
Australia	Microbial process	SIR	1	187	281	2		7.3					NEPC 2013b
Australia	Microbial process	SIR	1	462	693	2		4.9					NEPC 2013b
Australia	Microbial process	SIR	1	73	110	2		4.4					NEPC 2013b
Australia	Microbial process	SIR	1	499	749	2		5.0					NEPC 2013b
Australia	Microbial process	SIR	1	281	422	2		5.1					NEPC 2013b
Australia	Microbial process	SIR	1	25	38	2		6.3					NEPC 2013b
Australia	Microbial process	SIR	1	268	402	2		6.3					NEPC 2013b
Australia	Microbial process	SIR	1	345	518	2		4.8					NEPC 2013b
Australia	Microbial process	SIR	1	190	285	2		7.6					NEPC 2013b
Australia	Microbial process	SIR	1	158	237	2		5.4					NEPC 2013b
Europe	Urease	Urease	1	160	240	2		6.4	1.6		0.93		Doelman & Haanstra 1986

Appendix J – Raw data for DDT

Table 67 DDT toxicity data, including converted values, used to generate Eco-SGVs

Scientific or common name	Toxicity endpoint	NOEC/EC_{10} (mg/kg)	LOEC/EC30 (mg/kg)	Reference
Eisenia fetida	Reproduction	117.6	294	Hund-Rindke & Simon 2005
Folsomia candida	Reproduction	66.6	166.5	Hund-Rindke & Simon 2005
Phaseolus vulgaris	Growth	10	25	Pareek & Gaur 1970
Lolium perenne	Root length	483.62	1209.05	Chung et al 2007
Chlorococcum meneghini	Growth density	2.91	7.275	Chung et al 2007
Abruzzi rye	Tops yeidl (ww)	23.8	59.5	Boswell et al. 1955 in Environment Canada 1999g
Balbo rye	Tops yield (ww)	23.8	59.5	Boswell et al. 1955 in Environment Canada 1999g
Black Valentine beans	Vine yield	4.8	12	Boswell et al. 1955 in Environment Canada 1999g
Buckwheat	Yield (aerial portion)	31	77.5	Chisholm et al. 1955 in Environment Canada 1999g
Green beans	Yield	22	55	Chisholm et al. 1955 in Environment Canada 1999g
Mustard	Seedling height	20	50	Mitra and Raghu 1989 in Environment Canada 1999g
Netted Gem potatoes	Tuber yield	11.9	29.75	Boswell et al. 1955 in Environment Canada 1999g
Onions	Yield (bulbs)	72	180	Chisholm et al. 1955 in Environment Canada 1999g
Peanut	Seedling height	5	12.5	Mitra & Raghu 1989 in Environment Canada 1999g
Perfection peas	Plant & seed yield	11.9	29.75	Boswell et al. 1955 in Environment Canada 1999g
Purple top white Globe turnips	Tops yield	23.8	59.5	Boswell et al. 1955 in Environment Canada 1999g
Rutgers tomatoes	Plant yield	23.8	59.5	Boswell et al. 1955 in Environment Canada 1999g
Stringless Black Valentine beans	Plant yield	23.8	59.5	Boswell et al. 1955 in Environment Canada 1999g
Microathropods (mites etc)	Mortality	10	25	Perfect et al. 1981 in Environment Canada 1999g
Microarthropods (Collembola, Cryptopygus (Rhodanella) fasciatus	Mortality	50	125	Perfect et al. 1981 in Environment Canada 1999g
Hyperiodrylus spp.	Casting activity	5	12.5	Cook et al. 1980 in Environment Canada 1999g
Eudrilus spp.	Casting activity	5	12.5	Cook et al. 1980 in Environment Canada 1999g
Earthworms	Reduction in biomass	1	2.5	Thompson 1971 in Environment Canada 1999g
Microbes	Ammonification	1250	3125	Jones 1952 in Environment Canada 1999g
Microbes	Nitrate production	12.5	12.5	Eno & Everett 1958 in Environment Canada 1999g
Microbes	Nitrification/inhibition	1000	1000	Jones 1952 in Environment Canada 1999g

Appendix K – Raw data for total petroleum hydrocarbons

Table 68 Toxicity data used to generate ACLs for TPH fraction 1 (F1) and fraction 2(F2)

Species	Endpoint	LC/IC25	Reference
F1			
alfalfa	shoot weight	190	CCME 2008a
barley	shoot weight	490	CCME 2008a
corn	root length	160	CCME 2008a
Red fescue	root length	190	CCME 2008a
Orthonychirus folosmi	Reproduction	220	CCME 2008a
Eisenia andrei	mortality	510	CCME 2008a
F2			
alfalfa	shoot weight	167	CCME 2008a
barley	shoot weight	284	CCME 2008a
northern wheatgrass	root weight	79	CCME 2008a
Eisenia andrei	cocoon production	116	CCME 2008a
Orthonychirus folsomi	mortality	211	CCME 2008a

Appendix L – Raw data for fluoranthene and benzo(a)pyrene

Table 69 Toxicity data used to generate ACLs for fluoranthene and benzo(a)pyrene

Species	Endpoint	EC10	LOEC/EC30	E50	NOEC	LOEC	Reference
Fluoranthene							
Avena sativa	Growth		500	>1000			Kordel et al. 1984 in CCME 2008b
Brassica rapa	Growth		500	>1000			Kordel et al. 1984 in CCME 2008b
Eisenia veneta	Reproduction	113	282.5				Sverdrup et al. 2002 in CCME 2008b
Enchytraeus crypitcus	Reproduction		1212			1212	Achazi et al. 1995 in CCME 2008b
Enchytraeus crypitcus	Reproduction	15	37.5				Sverdrup et al. 2002b in CCME 2008b
Folsomia fimetaria	Reproduction	21	52.5				Sverdrup et al. 2002c in CCME 2008b
Benzo(a)pyrene							
Cannabis sativa	Emergence		44.5	89			Campbell et al. 2002 in CCME 2008b
Lupinus albus	Growth		155			>155	Henner et al. 1999 in CCME 2008b
Eisenia fetida	Growth	10	25				Achazi et al. 1995 in CCME 2008b
Eisenia fetida	Reproduction		5	10			Achazi et al. 1995 in CCME 2008b
Enchytraeus crypiticus	Reproduction		10			10.0928	Achazi et al. 1995 in CCME 2008b
Folsomia fimetaria	Reproduction	840	2100				Sverdrup et al. 2002a in CCME 2008b
Eisenia fetida	Growth	1	2.5				Duan et al. 2015
Eisenia fetida	Growth	10	25				Duan et al. 2015
Microbial processes	Basal respiration	25.6	64	>128			Hunde-Rinke & Simon 2005
Microbial processes	SIR		64	>128			Hunde-Rinke & Simon 2005
Microbial processes	PNR		64	>128			Hunde-Rinke & Simon 2005
Folsomia candida	Reproduction		64	>128			Hunde-Rinke & Simon 2005
Eisenia fetida	Reproduction		64	>128			Hunde-Rinke & Simon 2005
Brassica rapa	Growth		256	>512			Hunde-Rinke & Simon 2005
Avena sativa	Growth		256	>512			Hunde-Rinke & Simon 2005