National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April 2011 National Environment Protection (Assessment of Site Contamination) Measure April

Schedule B5c

GUIDELINE ON

Soil Quality Guidelines for Arsenic, Chromium (III), Copper, DDT, Lead, Naphthalene, Nickel & Zinc

The following guideline provides general guidance in relation to the framework for soil quality guidelines (for arsenic, chromium (III), copper, DDT, lead, napthalene, nickel and zinc) in the assessment of site contamination.

This Schedule forms part of the National Environment Protection (Assessment of Site Contamination) Measure as varied 2011 and should be read in conjunction with that document, which includes a policy framework and assessment of site contamination flowchart.

This Schedule, along with Schedule B5a and Schedule B5b replaces Schedule B5 to the National Environment Protection (Assessment of Site Contamination) Measure 1999.

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1 Introduction

1.1 Objectives

The objective of this guideline is to derive SQGs for As, Cu, Cr (III), DDT, naphthalene, Ni, Pb and Zn using the methodology detailed in Schedule B5b to:

- illustrate the flexibility of the methodology – being able to derive soil contaminant limits that provide different levels of protection, and use different toxicity data
- illustrate the magnitude and appropriateness of the soil contaminant limits
- compare the SQGs with those of overseas jurisdictions.

2 Overview of the method for deriving soil quality guidelines

The term 'soil quality guidelines' (SQGs) is used in this guideline to describe any concentration-based limit for contaminants in soils. Soil quality guidelines can have various purposes. For example, the National Environment Protection (Assessment of Site Contamination) Measure contains a specific type of SQG, the ecological investigation level (EIL), to guide how Australian contaminated sites should be assessed. The EILs were derived in such a manner that when they are exceeded it indicates that urban terrestrial ecosystems may experience harmful effects due to the presence of contaminants. The EILs are thus used to indicate when further investigation is necessary. However, SQGs with other purposes can and have been developed. For example, the Dutch have three sets of SQGs, each with a different purpose. These are target levels (their purpose is to indicate the long-term goals for the concentration of contaminants), maximum permissible levels (their purpose is to define the maximum acceptable level of contamination that is considered acceptable), and intervention levels (their purpose is to define the maximum permitted concentration before some immediate action is required).

As a result of consultation conducted in developing the methodology in November 2008, three different sets of ecotoxicity data were used to derive SOGs. The three sets of SQGs are termed $SQG_{(NOEC\ \&\ EC10)}$, $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ reflecting the type of ecotoxicity data that was used in their generation. A summary of the three types of SQGs to be derived, the data used and likely ecotoxicological effects that would be expected to occur if these are met is presented in Table 1. A combination of lowest observed effect concentration (LOEC) and 30% effect concentration data (EC30) has been adopted in the NEPM for the derivation of EILs.

Table 1. The relationship between the three types of soil quality guidelines (SQGs) to be generated, the data that are used to derive the SQGs and the type of toxic effects that would be experienced if the SQGs are met.

Type of soil quality guideline	Toxicity data used to calculate the soil quality guidelines	Expected toxic effects if the SQG is not exceeded
$SQG_{(NOEC\ \&\ EC10)}$	NOEC and EC10	slight toxic effects
$SQG_{(LOEC\ \&\ EC30)}$	LOEC and EC30	moderate toxic effects
$SQG_{(EC50)}$	EC50	significant toxic effects

An overview of the SQG derivation methodology (detailed in Schedule B5b is presented in Figure 1. One of the key aims in developing the methodology was to account for the availability and toxicity of the contaminant in the soil being studied. To do this, key soil and site-specific factors that are known to modify the toxicity of contaminants had to be accounted for. One factor that was incorporated into the methodology was the background concentration. In order to do this, the data used to derive the SQGs were expressed in terms of the amount of contaminant that had to be added to the soil to cause toxicity. When these toxicity data were used in accordance with the methodology the resulting value was termed the added contaminant level (ACL). An ambient background concentration (ABC) specific to the soil being investigated was then added to the ACL to calculate the SQG.

ACL values are generated as part of the methodology of deriving SQGs. Thus, it is necessary to differentiate the ACLs generated in deriving $SQG_{(NOEC \& EC10)}$ from those generated in deriving $SQG_{(LOEC \& EC30)}$ and $SQG_{(EC50)}$ values. The ACL generated in deriving an $SQG_{(NOEC \& EC10)}$ is termed the NOEC and EC10 based ACL ($ACL_{(NOEC \& EC10)}$). Similarly, ACLs generated in deriving $SQG_{(LOEC \& EC30)}$ and $SQG_{(EC50)}$ values are referred to as the LOEC and EC30 based ACL ($ACL_{(LOEC \& EC30)}$) and the EC50 based ACL ($ACL_{(EC50)}$).

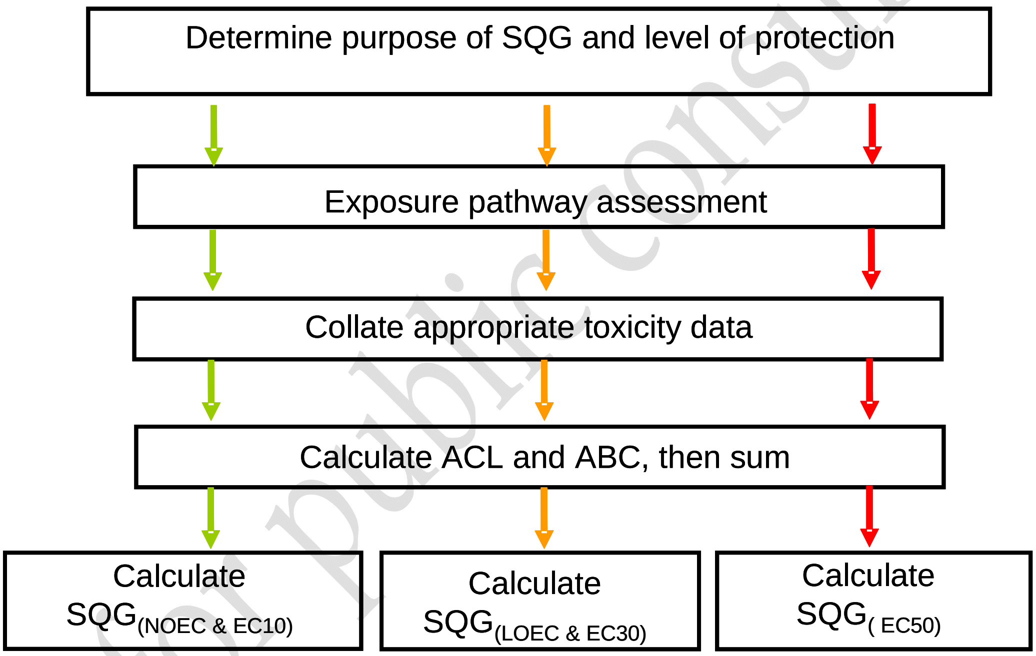

Figure 1. Overview of the methodology for deriving soil quality guidelines based on NOEC and EC10 data ($SQG_{(NOEC \& EC10)}$) indicated by the green (left most) arrows, based on LOEC and EC30 data ($SQG_{(LOEC \& EC30)}$) indicated by the orange (middle) arrows and based on EC50 data ($SQG_{(EC50)}$) indicated by the red (far right) arrows. As part of this process, ACLs and ABCs are calculated. The differences between the three SQGs are presented in Table 1.

The key steps in the methodology that are relevant to Cr (III), Cu, Pb and Ni for which SQGs were derived are:

1. Determining the purpose of the SQG and the appropriate level of protection.
2. Determining the most important exposure pathways.
3. Collating and screening the toxicity data.
4. Determining whether the contamination is fresh or aged and whether there are ageing/leaching factors available to account for this.
5. Normalising the toxicity data.
6. Calculating the ACL.
7. Accounting for biomagnification.

8. Measuring or calculating the ABC.
9. Calculating $SQG_{(NOEC\ \&\ EC10)}$, $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values for fresh contamination in soils with different land uses.
10. Calculating $SQG_{(NOEC\ \&\ EC10)}$, $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values for aged contamination in soils with different land uses.

These key steps and the decision pathway involved in deriving $ACL_{(NOEC\ \&\ EC10)}$ and $SQG_{(NOEC\ \&\ EC10)}$ values are provided in Figure 2 below. Exactly the same procedure would be used to derive $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values, except that different toxicity data would be used (Table 1). Details of the methodology for calculating SQGs are provided in Schedule B5b.

Land has a variety of potential uses, and the level of protection that is appropriate for each land use varies. For example, it is appropriate for a higher level of protection to be applied to national parks and areas with high ecological values compared to industrial land. The recommended levels of protection for various land uses are provided in Schedule B5b and are used in this guideline. The recommended level of protection when a contaminant does not biomagnify, for national parks/areas with high ecological value, urban residential/public open space and commercial/industrial, are 99%, 80% and 60% of species respectively. For contaminants that biomagnify, the recommended levels of protection for national parks/areas with high ecological value, urban residential/public open space and commercial/industrial are 99%, 85% and 65% of species. SQGs were generated for national park/area with high ecological value, urban residential land/public open space, and commercial/industrial land uses.

The contamination at many contaminated sites is not fresh, rather it has been there for many years. The biological availability (bioavailability) and toxicity of many contaminants decreases over time (that is, it ages) due to binding to soil particles, chemical and biological degradation and a range of other processes. Furthermore, in many laboratory-based ecotoxicity experiments which spike soils with soluble metal salts, ecotoxicity is overestimated due to a lack of leaching of soluble salts which affect metal sorption. These factors have been addressed in recent risk assessments for metals in soils using 'ageing/leaching' factors, and can be accounted for by multiplying the toxicity data by an ageing/leaching factor and thus deriving SQGs for aged contamination. Site-specific assessments of a contaminant's bioavailability can also be made, but these are usually conducted as part of a more detailed site-specific (Tier 2) ecological risk assessment. When ageing/leaching factors were available for the test chemicals examined in this study, SQGs were derived for aged contamination.

When contaminants are introduced to soil, some will bind strongly to the soil while others are mobile and will move off-site. Leaching to groundwater is a key off-site migration pathway and can result in aquatic ecosystems being exposed to contaminants. Therefore, the potential of contaminants to leach is an important characteristic that affects the environmental fate and effect they cause. The leaching potential is not controlled solely by the physicochemical properties of contaminants, but also by the properties of the soil containing the contaminant and climatic conditions. It is not possible or appropriate to account for the potential to leach in deriving practical SQGs at a generic level, rather this should be done as part of a more detailed site-specific ecological risk assessment.

Given the available data, the most complete set of SQGs was derived for each of the eight contaminants. A summary of what SQGs could be derived is presented below.

- For chromium (III), copper, nickel and zinc, it was possible to derive a set of soil-specific SQGs using each of the three types of toxicity data for each of the three land uses for both fresh and aged contamination.
- For arsenic and lead, it was possible to derive generic (not soil-specific) SQGs using each of the three types of toxicity data for each of the three land uses but for both fresh and aged contamination.
- For DDT and naphthalene, it was possible to derive generic (not soil-specific) SQGs using each of the three types of toxicity data for each of the three land uses but only for fresh contamination.

In addition, SQGs that account for the potential of contaminants to leach (and therefore should protect aquatic ecosystems) were derived for arsenic and zinc. This was only done for these contaminants to illustrate how this is done and what effect it has on the resulting SQGs compared to the SQGs that do not account for leaching.

2.1 Precision of estimates and rounding off added contaminant limits

In order to increase the readability and ease of use of this report the ACL, ABC and SQG values presented in the various tables have all been rounded off using the following scheme:

- all values < 1 were rounded off to the nearest 0.1
- all values between 1 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 nearent multiple of 10
- all values greater than 1000 were rounded off to the nearest 100 units.

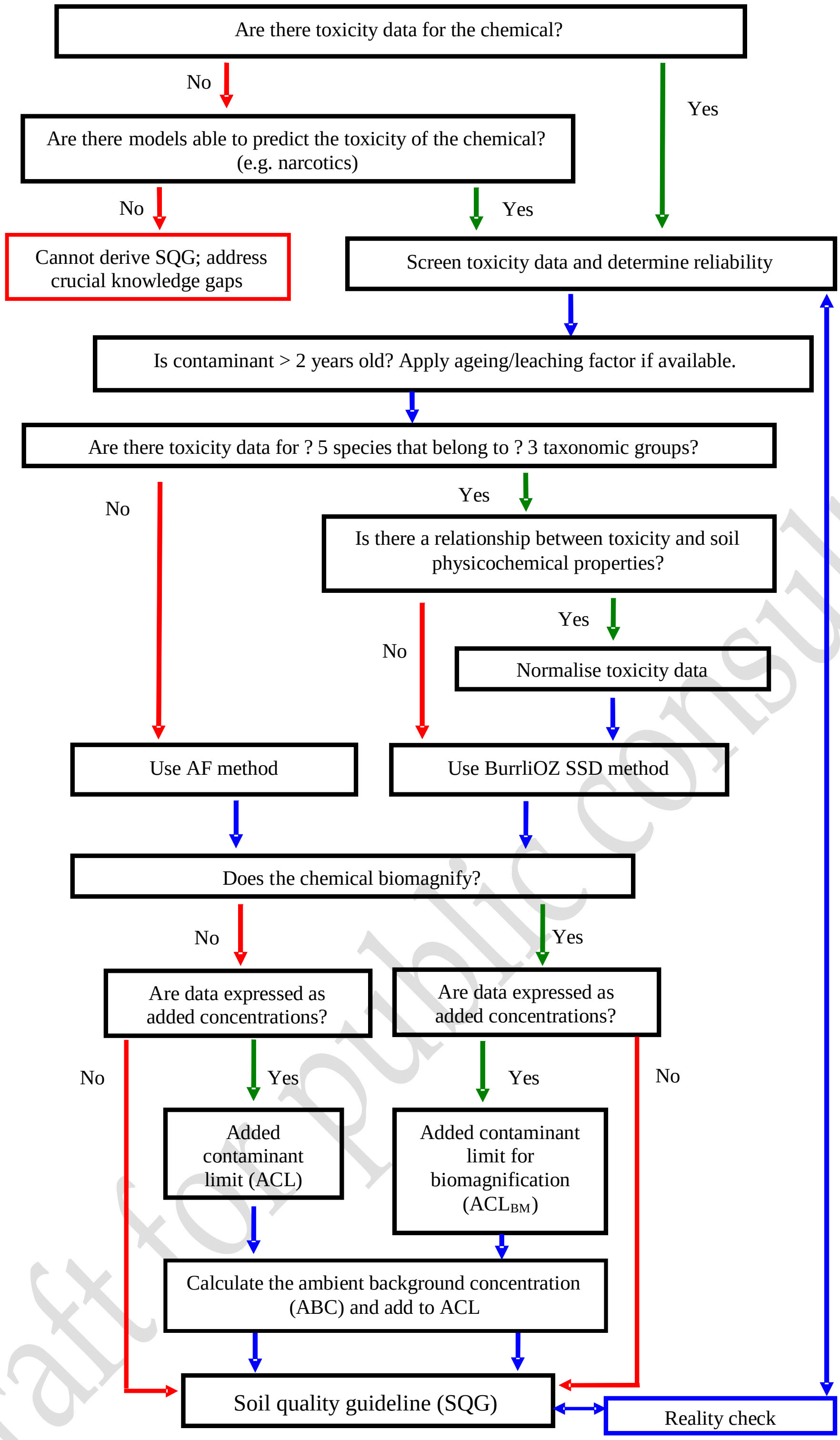

Figure 2. Schematic of the methodology for deriving soil quality guidelines (SQGs) (modified from Heemsbergen et al. 2008). Green arrows show the path when the preceeding question was answered with a 'yes' while the red arrows indicate the path when the answer was 'no'. Blue arrows indicate the path when there is no choice.

3 Zinc

3.1 Zinc compounds considered

The SQGs for Zn were derived using data for the following:

- Zinc metal (CAS No. 7440-66-6)
- Zinc oxide (CAS No. 1314-13-2)
- Zinc distearate (CAS Nos 557-05-1/91051-01-3)
- Zinc chloride (CAS No. 7646-85-7)
- Zinc sulphate (CAS No. 7733-02-0).

3.2 Exposure pathway assessment

The two key considerations in determining the most important exposure pathways for inorganic contaminants are whether they biomagnify (see glossary) and whether they have the potential to leach to groundwater.

A surrogate measure of the potential for a contaminant to leach is its water to soil partition coefficient (Kd). If the logarithm of the Kd (log Kd) of an inorganic contaminant is less than 3 then it is considered to have the potential to leach to groundwater (Schedule B5b). The Australian National Biosolids Research Program (NBRP) measured the log Kd of Zn in 17 agricultural soils throughout Australia. These measurements showed that in most soils the log Kd of Zn was below 3 L/kg (unpublished data). The log Kd value for Zn reported by Crommentuijn et al. (2000) was 2.2 L/kg. Therefore, there is the potential for Zn in some soils to leach to groundwater and affect aquatic ecosystems. However, the methodology for EIL derivation (Schedule B5b) does not advocate the routine derivation of EILs that account for leaching potential. Rather, it advocates that this is done on a site-specific basis as appropriate. However, the calculations of Zn SQGs that account for leaching have been included here as an illustration of the process and the effect that this has on the resulting soil quality guidelines.

Zinc is an essential element and, as such, concentrations of Zn in tissue are highly regulated and it does not biomagnify (Louma & Rainbow 2008; Schedule B5b). Therefore, the biomagnification route of exposure does not need to be considered for Zn and the SQGs will only account for direct toxicity.

3.3 Toxicity data

Zinc is a well studied inorganic contaminant and therefore a large dataset of toxicity values was available. Most studies presented their toxicity data in terms of added concentration (that is, the concentration of the contaminant added to the soil that causes a specified toxic effect) and so could be used without further modification. Some toxicity data were expressed in terms of total contaminant concentration but the background concentrations were reported. In such cases, the toxicity data was converted to an added concentration basis by subtracting the background from the total concentration. If toxicity data were expressed in terms of total contaminant concentration but the background concentration was not reported then the Dutch background correction equation — equation 1 (Lexmond et al. 1986) — was used to estimate the background concentration.

background Zn= 1.5*[2*organic matter (%) + clay content (%)] (*equation 1*)

The background concentration was then subtracted from the total concentration data to derive the added concentration toxicity value.

The toxicity database used to calculate the $SQG_{(NOEC\ \&\ EC10)}$ values for Zn included EC10 and NOEC toxicity data for nine soil processes (Table 2), 14 invertebrate species and 1 invertebrate community measurement (Table 3) and 22 plant species (Table 4). The raw data used to generate Tables 2–4 are provided in Appendix A. There were sufficient data (that is, toxicity data) for at least five species or soil processes that belong to at least three taxonomic or nutrient groups (Schedule B5b) available to derive $SQG_{(NOEC\ \&\ EC10)}$ values using a species sensitivity distribution (SSD) methodology. Given that Zn does not biomagnify, the level of protection recommended for non-biomagnifying contaminants was used to generate the SQG for each land use.

Table 2. The geometric mean values of the zinc toxicity data (expressed in terms of added Zn) for individual soil processes.

Soil process	Geometric means (mg/kg added Zn)		
	EC10 or NOEC	EC30 or LOEC	EC50
Acetate decomposition	187	280	560
Amidase	121	182	364
Ammonification	98	148	295
Arylsulphatase	289	434	868
Glucose decomposition	274	1169	2904
Nitrate reductase	56	84	168
Nitrification	455	706	930
Phosphatase	674	1011	2022
Respiration	104	157	313

Table 3. The geometric mean values of zinc (Zn) toxicity data (as added Zn) for soil invertebrate species and an invertebrate community.

Species/endpoint		Geometric means (mg/kg added Zn)		
Common name	Scientific name	EC10 or NOEC	EC30 or LOEC	EC50
Earthworm	*Aporrectodea caliginosa*	223	274	391
Earthworm	*Aporrectodea rosea*	390	407	436
Earthworm	*Eisenia fetida*	201	296	575
Earthworm	*Lumbriculus rubellus*	220	285	443
Earthworm	*Lumbriculus terrestris*	1062	1257	1675
Nematode	*Acrobeloides sp.*	221	332	663
Nematode	*Caenorhabditis elegans*	122	183	366
Nematode	*C. elegans* (dauer larvae)	689	1034	2068
Nematode	Community nematodes	306	459	919
Nematode	*Eucephalobus sp.*	135	202	403
Nematode	*Plectus sp.*	23	35	70
Nematode	*Rhabditidae sp.*	199	299	597
Potworm	*Enchytraeus albidus*	121	181	363
Potworm	*Enchytraeus crypticus*	276	414	828
Springtail	*Folsomia candida*	188	283	565

Table 4.The geometric mean values of the zinc (Zn) toxicity data (expressed in terms of added Zn) for individual plant species.

Plant species		Geometric means (mg/kg added Zn)		
Common name	**Scientific name**	**EC10 or NOEC**	**EC30 or LOEC**	**EC50**
Alfalfa	*Medicago sativa*	198	297	595
Barley	*Hordeum vulgare*	83	233	495
Beet	*Beta vulgaris*	198	297	595
Black or white lentil	*Vigna mungo*	95	142	284
Canola	*Brassica napus*	230	328	409
Common vetch	*Vicia sativa*	42	63	127
Cotton	*Gossypium sp.*	272	288	293
Fenugreek	*Trigonella foenum graecum*	106	159	318
Lettuce	*Latuca sativa*	264	396	793
Maize	*Zea mays*	202	304	581
Millet	*Panicum milaceum*	540	1580	2026
Oats	*Avena sativa*	222	333	667
Onion	*Allium cepa*	66	99	198
Pea	*Pisum sativum*	264	396	793
Peanuts	*Arachis hypogaea*	140	224	280
Red clover	*Trifolium pratense*	39	59	117
Sorghum	*Sorghum sp.*	123	254	444
Spinach	*Spinacia oleracea*	132	198	396
Sugar cane	*Sacharum*	3220	4830	9661
Tomato	*Lycopersicon esculentum*	264	396	793
Triticale	*Tritosecale sp.*	998	1364	1658
Wheat	*Triticum aestivum*	640	928	1172

3.4 Normalisation relationships

A normalisation relationship is an empirical model that predicts the toxicity of a single contaminant to a single species using soil physicochemical properties (for example, soil pH and organic carbon content). Seven normalisation relationships were reported in the literature for Zn toxicity (Table 5). Three were developed for Australian soils (Broos et al. 2007; Warne et al. 2008a; Warne et al. 2008b) and four have been derived for European soils (Lock & Janssen 2001; Smolders et al. 2003). Three of the relationships were for plants, two for microbial functions and two for soil invertebrates (Table 5). Of these, relationships 1-4, 6 & 7 were used to derive Zn SQGs. Relationship number 5 for wheat was not used as an equivalent field-based relationship for Australian soils was available and field-based normalisation relationships provide better estimates of toxicity in the field (Warne et al. 2008a) and thus are preferred to laboratory-based relationships (Schedule B5b).

Normalisation relationships are used to account for the effect of soil characteristics on toxicity data, so the resulting toxicity data more closely reflect the inherent sensitivity of the test species. All the Zn toxicity data in Tables 2–4 were normalised to their equivalent toxicity in the recommended Australian reference soil (Schedule B5b) (Table 6). Depending on the conditions under which the toxicity tests were conducted, the normalised toxicity data could be higher or lower in the reference soil compared to the original toxicity data in the test soil.

Table 5. Normalisation relationships for the toxicity of zinc to soil invertebrates, soil processes and plants.

Eqtn no.	Species/soil process	Y parameter	X parameter(s)	Reference
1	*E. fetida* (earthworm)	log EC50	0.79* log CEC	Lock and Janssen 2001
2	*F. candida* (collembola)	log EC50	1.14* log CEC	Lock and Janssen 2001
3	PNR	log EC50	0.15*pH	Smolders et al. 2003
4	SIN	log EC50	0.34*pH + 0.93	Broos et al. 2007
5	*T. aestivum* (wheat)	log EC10	0.14 * pH + 0.89*log OC + 1.67	Warne et al. 2008a
6		log EC10	0.271*pH +0.702*CEC + 0.477	Warne et al. 2008b
7		log EC50	0.12*pH +0.89* log CEC + 1.1	Smolders et al. 2003

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

Table 6. Values of soil characteristics for the recommended Australian reference soil to be used to normalise toxicity data

Soil property	Value
pH	6
Clay (%)	10
CEC ($cmol_c$/kg)	10
Org. Carbon (%)	1

CEC – cation exchange capacity, org.carbon = organic carbon content.

3.5 Sensitivity of organisms to zinc

The toxicity data (geometric means) used by the SSD method to calculate the ACL are shown in Table 2 for soil processes, Table 3 for soil invertebrates and Table 4 for plants. Figure 3 shows the SSD (that is, a cumulative distribution of the geometric means of the species) for all species for which there were Zn toxicity data. Toxicity data for plants, soil processes and soil invertebrates were evenly spread in the SSD, which indicate that these groups of organisms all have a similar sensitivity to Zn. Therefore, all the toxicity data were used to derive the ACLs, thus increasing the number of data used in the SSD method and increasing the reliability of the ACL values.

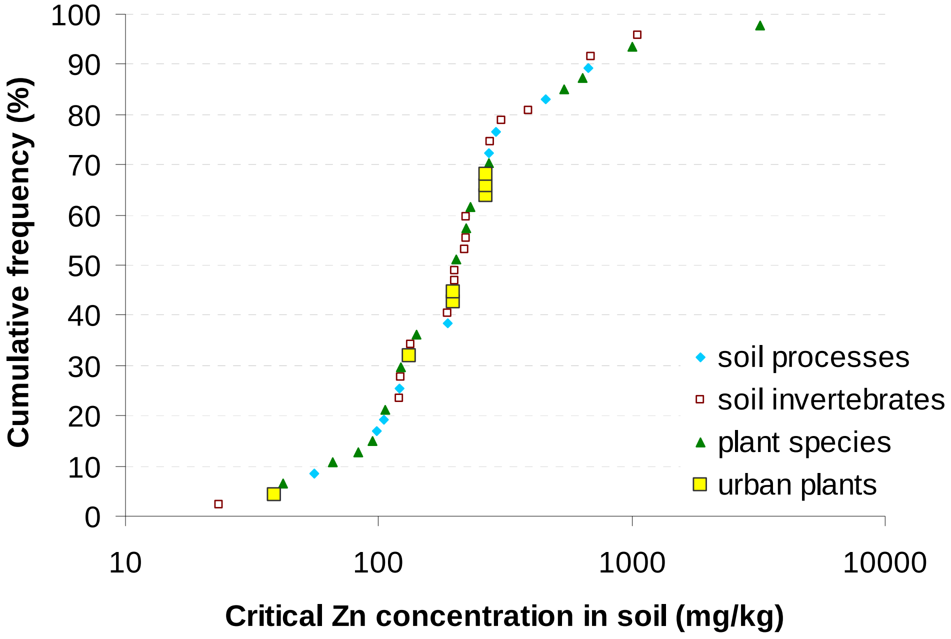

Figure 3. The species sensitivity distribution (plotted as a cumulative frequency against added zinc (Zn) concentration) for soil processes, soil invertebrates and plant species to Zn.

3.6 Calculation of soil quality guidelines for fresh zinc contamination

Soil quality guidelines were derived for fresh zinc contamination using three different sets of toxicity data: NOEC & EC10; LOEC and EC30; and EC50. The methods by which they were calculated and the resulting ACL and SQG values are presented in the following sections.

3.6.1 Calculation of soil quality guidelines for fresh zinc contamination based on no observed effect concentration and 10% effect concentration toxicity data

3.6.1.1 Calculation of soil-specific added contaminant limits

The NOEC and EC10 toxicity data were normalised using the equations presented in Table 5 to the Australian reference soil (Table 6) and then the lowest geometric mean for each species/soil microbial process was entered into the BurrliOZ species sensitivity distribution (Campbell et al. 2000) method. The SSD generated a single numerical value (that is, the $ACL_{(NOEC\ \&\ EC10)}$ for each desired level of protection. These $ACL_{(NOEC\ \&\ EC10)}$ values only apply to the Australian reference soil.

The $ACL_{(NOEC\ \&\ EC10)}$ value for the Australian reference soil with an urban residential land/public open space use was approximately 100 mg/kg. These $ACL_{(NOEC\ \&\ EC10)}$ values for the reference soil were then used to calculate $ACL_{(NOEC\ \&\ EC10)}$ values for a range of soils (that is, soil-specific $ACL_{(NOEC\ \&\ EC10)}$) for each group of organisms using the same normalisation relationships as before but in the reverse manner. The following explains how the soil-specific $ACL_{(NOEC\ \&\ EC10)}$ values for soils with an urban residential /public open space land use were calculated as an example of how this was done for each of the land uses. Soil-specific $ACL_{(NOEC\ \&\ EC10)}$ values for soil processes varied with soil pH and ranged from 20 to 330 mg/kg added Zn for soils with pHs between 4 and 7.5 (Table 7). The soil-specific $ACL_{(NOEC\ \&\ EC10)}$ values for invertebrates (Table 8) varied with cation exchange capacity (CEC), with values ranging from 60 to 420 mg/kg for soils with CEC values ranging from 5 to 60 $cmol_c$/kg. Soil-specific $ACL_{(NOEC\ \&\ EC10)}$ values for plants (Table 9) were pH and CEC specific and ranged from 20 to 910 mg/kg for soils with pHs between 4 and 7.5 and CEC values between 5 and 60 $cmol_c$/kg.

Table 7. Soil-specific ACL values for zinc (Zn) based on no observed effect concentration and 10% effect concentration toxicity data that should theoretically protect 80% of soil processes in soils with pH values ranging from 4.0 to 7.5.

Soil pH	Zn ACLs (mg/kg) for soil processes
4.0	20
4.5	30
5.0	45
5.5	70
6.0	100
6.5	150
7.0	220
7.5	330

Table 8. Soil-specific ACL values for zinc (Zn) based on no observed effect concentration and 10% effect concentration toxicity data that should theoretically protect 80% of invertebrate species in soils with CEC ranging from 5 to 60 $cmol_c$/kg.

Cation exchange capacity ($cmol_c$/kg)	Zn ACL (mg/kg) for invertebrates
5	60
10	100
20	180
30	240
40	300
60	420

Table 9. Soil-specific ACL values for zinc (Zn) based on no observed effect concentration and 10% effect concentration toxicity data that should theoretically protect 80% of plant species in soils with pH values ranging from 4.0 to 7.5 and CEC values ranging from 5 to 60 $cmol_c$/kg.

pH	CEC ($cmol_c$/kg)					
	5	10	20	30	40	60
4.0	20	30	50	65	75	100
4.5	25	40	65	85	110	140
5.0	35	55	90	120	140	190
5.5	45	75	120	160	200	260
6.0	65	100	170	220	270	360
6.5	85	140	230	300	370	490
7.0	120	190	310	410	500	670
7.5	160	260	420	560	690	910

These soil-specific $ACL_{(NOEC \& EC10)}$ values for each organism group (presented in Tables 7 to 9) were then merged into a single set of soil-specific $ACL_{(NOEC \& EC10)}$ values – so that the lowest $ACL_{(NOEC \& EC10)}$ value for each combination of soil pH and CEC was adopted (Table 10). It is important to note that the $ACL_{(NOEC \& EC10)}$ values presented in Table 10 are the recommended $ACL_{(NOEC \& EC10)}$ values for Zn as they should protect at least 80% of soil processes, soil invertebrate and plant species and these ranged from 20 to 330 mg/kg in soils with pH values between 4 and 7.5 and CEC values between 5 and 60 $cmol_c$/kg. The $ACL_{(NOEC \& EC10)}$ values presented in Tables 7-9 are the ACLs for individual groups of organisms and are not the recommended ACLs.

Table 10. Soil-specific added contaminant limits based on no observed effect concentration and 10% effect concentration toxicity data ($ACL_{(NOEC\ \&\ EC10)}$, mg/kg) for zinc (Zn) that theoretically protect at least 80% of soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.0 to 7.5 and CEC values ranging from 5 to 60 cmolc/kg. These are the recommended ACLs for Zn in freshly contaminated soils with an urban residential /public open space land use.

pH	CEC ($cmol_c$/kg)					
	5	10	20	30	40	60
4.0	20	20	20	20	20	20
4.5	25	30	30	30	30	30
5.0	35	45	45	45	45	45
5.5	45	70	70	70	70	70
6.0	60	100	100	100	100	100
6.5	60	100	150	150	150	150
7.0	60	100	180	220	220	220
7.5	60	100	180	240	300	330

The same methods as described above were used to generate the recommended ACL (NOEC & EC10) values for the national park/area with high ecological value and commercial/industrial land uses. The ACL (NOEC & EC10) values for these land uses are presented in Tables 11 and 12.

Table 11. Soil-specific added contaminant limits based on no observed effect concentration and 10% effect concentration toxicity data ($ACL_{(NOEC\ \&\ EC10)}$, mg/kg) for zinc (Zn) that theoretically protect at least 99% of soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.0 to 7.5 and CEC values ranging from 5 to 60 cmolc/kg. These are the recommended ACLs for Zn in freshly contaminated soils with a national park/area with high ecological value land use.

pH	CEC ($cmol_c$/kg)					
	5	10	20	30	40	60
4.0	4	5	5	5	5	5
4.5	6	8	8	8	8	8
5.0	8	10	10	10	10	10
5.5	10	15	15	15	15	15
6.0	15	25	25	25	25	25
6.5	15	25	35	35	35	35
7.0	15	25	45	55	55	55
7.5	15	25	45	60	75	80

Table 12. Soil-specific added contaminant limits based on no observed effect concentration and 10% effect concentration toxicity data ($ACL_{(NOEC\ \&\ EC10)}$, mg/kg) for zinc (Zn) that theoretically protect at least 60% of soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.0 to 7.5 and cation exchange capacity (CEC) values ranging from 5 to 60 $cmol_c$/kg. These are the recommended ACLs for Zn in freshly contaminated soils with a commercial/industrial land use.

pH	CEC ($cmol_c$/kg)					
	5	10	20	30	40	60
4.0	30	35	35	35	35	35
4.5	40	50	50	50	50	50
5.0	55	75	75	75	75	75
5.5	75	110	110	110	110	110
6.0	95	160	160	160	160	160
6.5	95	160	240	240	240	240
7.0	95	160	280	350	350	350
7.5	95	160	280	390	480	520

3.6.1.2 *Calculation of ABC values*

To convert ACLs to SQGs, the ABC needs to be added to the ACL. Three methods of determining the ABC were recommended in the methodology for deriving SQGs (Schedule B5b). The preferred method is to measure the ABC at an appropriate reference site. However, where this is not possible the methods of Olszowy et al. (1995) and Hamon et al. (2004) were recommended, depending on the situation. For sites with no history of contamination the method of Hamon et al. (2004) was recommend to estimate the ABC. In this method, the ABC for Zn varies with the soil iron concentration (Table 13). Predicted ABC values for Zn range from 3 to 62 mg/kg in soils with iron concentrations between 0.1 and 20%. For aged contaminated sites (i.e. the contamination has been in place for at least two years, see Schedule B5b) the methodology recommends using the 25^{th} percentiles of the ABC data for the 'old suburbs' of Olszowy et al. (1995) (see Table 14). The ABC values for Zn in 'new suburbs' (Olszowy et al. 1995) were similar to the values predicted by the Hamon et al. (2004) method. Therefore it is recommended that the Hamon et al. (2004) method be used to generate ABC values for new suburbs (that is, < 2 years old) as soil-specific values will be generated, while for old suburbs with aged contamination (that is, > 2 years) it was recommended that the 25^{th} percentile of the ABC data from old suburbs (Olszowy et al. 1995) be used.

Table 13. Zinc (Zn) ABC calculated using the Hamon et al. (2004) method.

Soil iron content (%)	Zn ABC (mg/kg)
0.1	3
1	10
10	40
20	60

Table 14. Zinc (Zn) ABC based on the 25 percentiles of Zn concentrations in 'old suburbs' (i.e. > 2 years old) from various states of Australia (Olszowy et al. 1995).

Suburb type	25^{th} percentile of Zn ABC values (mg/kg)			
	NSW	QLD	SA	VIC
New suburb low traffic	25	15	25	15
New suburb high traffic	45	30	30	20
Old suburb low traffic	75	80	55	40
Old suburb high traffic	120	160	90	55

3.6.1.3 *Examples of soil quality guidelines for fresh zinc contamination based on no observed effect concentration and 10% effect concentration data*

To calculate a $SQG_{(NOEC \& EC10)}$, the ABC value is added to the $ACL_{(NOEC \& EC10)}$. ABC values vary with soil type. Therefore, it is not possible to present a single set of $SQG_{(NOEC \& EC10)}$ values. Thus, two examples of $SQG_{(NOEC \& EC10)}$ values for urban contaminated soils are provided below. These examples would be at the low and high end of the range of SQGs values (but not the extreme values) generated for Australian soils.

Example 1

Site descriptors - urban residential/public open space land use use in a new suburb.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with a 1% iron content.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:

$ACL_{(NOEC \& EC10)}$:	45 mg/kg
ABC:	10 mg/kg
$SQG_{(NOEC \& EC10)}$:	55 mg/kg

Example 2

Site descriptors – commercial/industrial land use in a new suburb.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:

$ACL_{(NOEC \& EC10)}$:	480 mg/kg[1]
ABC:	40 mg/kg
$SQG_{(NOEC \& EC10)}$:	520 mg/kg

3.6.2 Calculation of soil quality guidelines based on protecting aquatic ecosystems from leaching of fresh zinc contamination

As indicated in the exposure pathway assessment, the log Kd values for Zn measured in a range of Australian soils were below 3 and therefore there is the potential in some soils for Zn to leach to groundwater and effect aquatic ecosystems. Although the calculation of SQGs based on protecting aquatic ecosystems from the effects of leached contaminants is not included in the EIL derivation methodology (Schedule B5b), the calculations are presented here to illustrate the recommended approach and what effect this has on the resulting SQGs. The following SQGs were based on the $ACL_{(NOEC \& EC10)}$ values for urban residential/public open space land use.

The soil-specific SQGs for Zn that accounted for leaching potential were calculated using the US EPA method (US EPA, 1996).

$$SQG = C_w \cdot (Kd + (\theta_w + \theta_a \cdot H') / \rho_b) \cdot DAF \qquad \textit{(equation 2)}$$

where SQG is the appropriate soil quality guideline in soil (mg/kg), C_w is the target soil leachate concentration (mg/L) (that is, the Australian and New Zealand freshwater quality guideline for Zn, ANZECC and ARMCANZ, 2000), Kd is the soil to water partition coefficient (L/kg), θ_w is the water filled soil porosity L_{water}/L_{soil}), θ_a is the air filled soil porosity (L_{air}/L_{soil}), ρ_b is the dry soil bulk density (kg/L), H' is the Henry's law constant (unitless), and DAF is the dilution and attenuation factor[2]. The values of DAF used in the calculations were 1 and 20. There is a linear relationship between the DAF and the SQGs, thus the SQGs calculated using a DAF of 20 are 20 times larger than those calculated using a DAF of 1.

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[1] The soil-specific Zn ACLs for commercial/industrial land use are provided in Appendix B, Table 1.

2 Soil pore water is the predominant source of groundwater. As the soil pore water leaches it passes through material which can bind the contaminants (attenuation) thus reducing their concentration. Also, in the majority of cases groundwater catchments will contain both contaminated and uncontaminated soils, pore water from the contaminated soil will be diluted by that from the uncontaminated (dilution). Therefore a a dilution attenuation factor (DAF) is used to convert soil pore water concentrations to groundwater concentrations. The fraction of contaminated land to the total area of the groundwater/aquifer catchment can be used to calculate the DAF as indicated below:

$$DAF = 100 \div \text{percentage of contaminated soil in catchment} \qquad (B1)$$

The value for θ_w was set to 0.1 L_{water}/L_{soil}, θ_a was set to 0.1 L_{air}/L_{soil}, ρ_b was set to 1.3 kg/L and the reference soil setting for organic carbon is 0.01%. The calculated SQG values when DAF was 1 and 20 are presented in Tables 15 and 16 respectively.

Table 15. Soil-specific zinc (Zn) soil quality guidelines ($SQG_{(NOEC \& EC10)}$, mg total Zn/kg) based on protecting groundwater ecosystems from groundwater leaching when the dilution and attenuation factor (DAF) was one.

pH	CEC (cmol$_c$/kg)					
	5	10	20	30	40	60
4	0.1	0.1	0.3	0.6	0.9	2
5	0.1	0.3	0.9	2	2	4
6	0.3	0.8	2	4	6	10
7	0.8	2	6	10	15	30
8	2	5	15	25	40	75

Table 16. Soil-specific zinc (Zn) soil quality guidelines (SQG(NOEC & EC10), mg total Zn/kg) based on protecting groundwater ecosystems from groundwater leaching when the dilution and attenuation factor (DAF) was 20.

pH	CEC (cmol$_c$/kg)					
	5	10	20	30	40	60
4	1	2	7	10	20	35
5	2	6	15	30	50	85
6	6	15	45	80	120	220
7	15	40	115	210	310	570
8	40	110	300	530	810	1500

3.6.3 Calculation of soil quality guidelines for fresh zinc contamination based on lowest observed effect concentration and 30% effect concentration toxicity data and based on 50% effect concentration toxicity data

In addition to calculating $SQG_{(NOEC \& EC10)}$ values, two other sets of SQGs corresponding to two other levels of protection were generated. T hese were the $SQG_{(LOEC \& EC30)}$ which indicate concentrations above which moderate toxic effects would occur and the $SQG_{(EC50)}$ which indicate concentrations above which marked toxic effects would occur.

3.6.3.1 Calculation of soil-specific added contaminant limits

The Zn $SQG_{(LOEC\ and\ EC30)}$ and $SQG_{(EC50)}$ and associated ACL values were calculated using the methodology, except the input data for the SSD were changed to the appropriate type (Table 1). These data are presented in Tables 2-4 and the raw data can be found in Appendix A. These measures of toxicity were not available in all instances, therefore, to maximise the data available to calculate $SQG_{(LOEC\ and\ EC30)}$ and $SQG_{(EC50)}$ values the available toxicity data were converted to these measures using conversion factors. The NBRP (cited in Heemsbergen et al., 2008) derived a set of conversion factors for Cu and Zn (Table 17). These experimentally-based conversion factors were used rather than the generic conversion factors presented in Heemsbergen et al. (2008), which is consistent with the approach recommended in the methodology for deriving SQGs (Heemsbergen et al., 2008). Table 18 shows the $ACL_{(LOEC \& EC30)}$ and $ACL_{(EC50)}$ values for the Australian reference soil (that is, a pH of 6 and a cation exchange capacity of 10 cmol$_c$/kg) with national park/area with high ecological value, urban residential/public open space, and commercial/industrial land uses. The set of soil-specific Zn $ACL_{(LOEC \& EC30)}$ and $ACL_{(EC50)}$ values for each land use are presented in Tables 19 and 20.

Table 17. 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 Heemsbergen et al. (2008).

Data being converted	Conversion factor
NOEC or EC10 to EC50	x 3
NOEC or EC10 to LOEC or EC30	x 1.5
LOEC or EC30 to EC50	x 2

Table 18. Zinc (Zn) added contaminant levels based on lowest observed effect concentration and 30% effect concentration data (ACL(LOEC & EC30)) and based on 50% effect concentration data (ACL(EC50)) for the Australian reference soil with various land uses.

Land use	$ACL_{(LOEC\& EC30)}$ values (mg/kg added Zn)	$ACL_{(EC50)}$ values (mg/kg added Zn)
National park/area with high ecological value	40	80
Urban residential/public open space	160	290
Commercial/industrial	250	450

Table 19. Soil-specific added contaminant limits based on lowest observed effect concentration and 30% effect concentration toxicity data ($ACL_{(LOEC\ \&\ EC30)}$, mg/kg) for fresh zinc (Zn) that should theoretically provide the appropriate level of protection (that is, 99, 80 or 60% of species) to soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.0 to 7.5 and CEC values ranging from 5 to 60 $cmol_c$/kg. These are the recommended $ACL_{(LOEC\ \&\ EC30)}$ values for Zn in freshly contaminated soils with each land use.

National park/area with high ecological value land use

pH	CEC ($cmol_c$/kg)					
	5	10	20	30	40	60
4.0	7	8	8	8	8	8
4.5	10	10	10	10	10	10
5.0	15	20	20	20	20	20
5.5	20	25	25	25	25	25
6.0	25	40	40	40	40	40
6.5	25	40	60	60	60	60
7.0	25	40	70	90	90	90
7.5	25	40	70	95	120	130

Urban residential/public open space land use

pH	CEC ($cmol_c$/kg)					
	5	10	20	30	40	60
4.0	25	30	30	30	30	30
4.5	35	50	50	50	50	50
5.0	50	70	70	70	70	70
5.5	70	100	100	100	100	100
6.0	90	150	150	150	150	150
6.5	90	150	230	230	230	230
7.0	90	150	270	340	340	340
7.5	90	150	270	370	460	500

Commercial/industrial land use						
pH	**CEC ($cmol_c$/kg)**					
	5	**10**	**20**	**30**	**40**	**60**
4.0	45	50	50	50	50	50
4.5	60	75	75	75	75	75
5.0	80	110	110	110	110	110
5.5	110	170	170	170	170	170
6.0	140	250	250	250	250	250
6.5	140	250	360	360	360	360
7.0	140	250	420	540	540	540
7.5	140	250	420	590	730	800

Table 20. Soil-specific added contaminant limits based on 50% effect concentration toxicity data ($ACL_{(EC50)}$, mg/kg) for fresh zinc (Zn) that should theoretically provide the appropriate level of protection (that is, 99, 80 or 60% of species) to soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.0 to 7.5 and cation exchange capacity (CEC) values ranging from 5 to 60 $cmol_c$/kg. These are the recommended $ACL_{(EC50)}$ for Zn in freshly contaminated soils with each land use.

National park/area with high ecological value land use						
pH	**CEC ($cmol_c$/kg)**					
	5	**10**	**20**	**30**	**40**	**60**
4.0	15	15	15	15	15	15
4.5	20	25	25	25	25	25
5.0	25	35	35	35	35	35
5.5	35	55	55	55	55	55
6.0	45	80	80	80	80	80
6.5	45	80	110	110	110	110
7.0	45	80	130	170	170	170
7.5	45	80	130	190	230	250

Urban residential/public open space land use						
pH	**CEC ($cmol_c$/kg)**					
	5	**10**	**20**	**30**	**40**	**60**
4.0	50	60	60	60	60	60
4.5	70	90	90	90	90	90
5.0	95	130	130	130	130	130
5.5	130	200	200	200	200	200
6.0	170	290	290	290	290	290
6.5	170	290	430	430	430	430
7.0	170	290	500	640	640	640
7.5	170	290	500	690	870	940

Commercial/industrial land use						
pH	**CEC ($cmol_c$/kg)**					
	5	**10**	**20**	**30**	**40**	**60**
4.0	80	95	95	95	95	95
4.5	100	150	150	150	150	150
5.0	150	200	200	200	200	200
5.5	200	300	300	300	300	300
6.0	250	450	450	450	450	450
6.5	259	450	650	650	650	650
7.0	259	450	750	1000	1000	1000
7.5	259	450	750	1100	1300	1400

3.6.3.2 Calculation of ambient background concentration values

The ABC values for freshly contaminated soils were calculated using the method set out in this Schedule and presented in Table 13.

3.6.3.3 Examples of soil quality guidelines for fresh copper contamination based on no observed effect concentration and 10% effect concentration data

In order to calculate the $SQG_{(LOEC \& EC30)}$ and $SQG_{(EC50)}$ values the soil-specific ABC has to be added to the $ACL_{(LOEC \& EC30)}$ and $ACL_{(EC50)}$ values, respectively. Therefore, the $SQG_{(LOEC \& EC30)}$ and $SQG_{(EC50)}$ values will always be at least as large as those presented in Tables 19 and 20. Examples of the $SQG_{(LOEC \& EC30)}$ and $SQG_{(EC50)}$ values are provided below.

$SQG_{(LOEC \& EC30)}$ - Example 1

Site descriptors - urban residential/public open space land use in a new suburb.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with a 1% iron content.

The resulting $ACL_{(LOEC \& EC30)}$, ABC and $SQG_{(LOEC \& EC30)}$ values are:

$ACL_{(LOEC \& EC30)}$	70	mg/kg
ABC	10	mg/kg
$SQG_{(LOEC \& EC30)}$	80	mg/kg

$SQG_{(LOEC \& EC30)}$ - Example 2

Site descriptors – commercial/industrial land use in a new suburb.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(LOEC \& EC30)}$, ABC and $SQG_{(LOEC \& EC30)}$ values are:

$ACL_{(LOEC \& EC30)}$	730	mg/kg
ABC	40	mg/kg
$SQG_{(LOEC \& EC30)}$	770	mg/kg

$SQG_{(EC50)}$ - Example 3

Site descriptors - urban residential/public open space land use in a new suburb.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with a 1% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$	130	mg/kg
ABC	10	mg/kg
$SQG_{(EC50)}$	140	mg/kg

$SQG_{(EC50)}$ - Example 4

Site descriptors - commercial/industrial land use in a new suburb.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$	1300	mg/kg
ABC	40	mg/kg
$SQG_{(EC50)}$	1340	mg/kg

3.7 Calculation of soil quality guidelines for aged zinc contamination

3.7.1 Calculation of an ageing and leaching factor for zinc

In addition to calculating SQGs in recently contaminated soils (that is, contamination is < 2 years old), an equivalent set of levels were derived for soils where the contamination is aged (that is, it has been present for ≥ 2 years). The Zn $SQG_{(NOEC\ \&\ EC10)}$, $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ for aged sites were calculated using the methods set out in Schedule B5b and this Schedule, the only difference being that laboratory toxicity data based on freshly spiked soils or soils that had not been leached were multiplied by an ageing/leaching factor. A factor (that is, three for Zn) was developed by Smolders et al. (2009) that accounted for ageing and leaching of various metals. This ageing and leaching factor (ALF) has been incorporated into the methodology to derive the Flemish soil quality guidelines (Vlarebo 2008). Therefore, the raw toxicity data (Appendix A) for Zn that were generated using freshly spiked and non-leached soils were multiplied by this conversion factor and the geometric means for each species and soil process re-calculated (Tables 21–23). It should be noted that the values in Tables 21–23 are not simply the data from Tables 2–4 multiplied by three – as the correction factor was not applied to all the data (for example, data from the field-based NBRP were not adjusted).

3.7.2 Calculation of soil quality guidelines for aged zinc contamination based on no observed effect concentration and 10% effect concentration toxicity data

3.7.2.1 Calculation of added contaminant limits for aged zinc contamination based on no observed effect concentration and 10% effect concentration toxicity data

The lowest geometric mean of the age-corrected toxicity data for each species/soil microbial process that were used to derive the aged $ACL_{(NOEC\ \&\ EC10)}$ values are presented in Table 21 for soil processes, Table 22 for soil invertebrate species, and Table 23 for plant species. The conversion of the fresh toxicity data to account for ageing/leaching and the resulting toxicity values are presented in Appendix A.

Table 21. The geometric mean values of the aged and age-corrected zinc (Zn) toxicity data (expressed in terms of added Zn) for soil processes.

Soil process	Geometric means (mg/kg added Zn)		
	EC10 or NOEC	EC30 or LOEC	EC50
Acetate decomposition	561	841	1681
Amidase	363	545	1091
Ammonification	295	443	885
Arylsulphatase	868	1303	2605
Glucose decomposition	274	1169	2904
Nitrate reductase	168	252	504
Nitrification	455	706	930
Phosphatase	2022	3033	6066
Respiration	313	470	940

Table 22. The geometric mean values of the aged and age-corrected zinc (Zn) toxicity data (expressed in terms of added Zn) for soil invertebrate species.

Invertebrate species		Geometric means (mg/kg added Zn)		
Common name	Scientific name	EC10 or NOEC	EC30 or LOEC	EC50
Earthworm	*A. caliginosa*	669	823	1172
Earthworm	*A. rosea*	1172	1221	1308
Earthworm	*E. fetida*	602	888	1726
Earthworm	*L. rubellus*	659	855	1328
Earthworm	*L. terrestris*	3187	3771	5026
Nematode	*Acrobeloides sp.*	663	995	1989
Nematode	*C. elegans*	366	550	1099
Nematode	*C. elegans* (dauer larval stage)	2068	3103	6205
Nematode	Community nematodes	919	1378	2756
Nematode	*Eucephalobus sp.*	404	605	1210
Nematode	*Plectus sp.*	70	105	210
Nematode	*Rhabditidae sp.*	597	896	1791
Potworm	*E. albidus*	363	544	1088
Potworm	*E. crypticus*	828	1241	2483
Springtail	*F. candida*	566	848	1696

Table 23. The geometric mean values of the aged and age-corrected zinc (Zn) toxicity data (expressed in terms of added Zn) for plant species.

Species	Scientific name	Geometric means (mg/kg added Zn)		
		EC10 or NOEC	EC30 or LOEC	EC50
Alfalfa	*M. sativa*	595	892	1784
Barley	*H. vulgare*	110	306	652
Beet	*B.vulgaris*	595	892	1784
Black or white lentil	*V. mungo*	284	426	852
Canola	*B. napus*	230	328	409
Common vetch	*V. sativa*	127	190	380
Cotton	*Gossypium sp.*	272	288	293
Fenugreek	*T. foenum graecum*	318	477	953
Lettuce	*L. sativa*	793	1189	2379
Maize	*Z. mays*	460	694	1324
Millet	*P. milaceum*	540	1580	2026
Oats	*A. sativa*	667	1000	2000
Onion	*A. cepa*	198	297	594
Pea	*P. sativum*	793	1189	2379
Peanuts	*A. hypogaea*	140	224	280
Red clover	*T. pratense*	117	176	351
Sorghum	*Sorghum sp.*	256	528	924
Spinach	*S. oleracea*	396	595	1189
Sugar cane	*Sacharum*	3220	4830	9661
Tomato	*L. esculentum*	793	1189	2379
Triticale	*Tritosecale sp.*	998	1364	1658
Wheat	*T. aestivum*	640	928	1172

For each urban residential/public open space land use, soil-specific ACL$_{(NOEC\ \&\ EC10)}$ values were derived separately for soil processes, soil invertebrate species and plant species (data not shown). Within each land use type, the soil-specific ACL$_{(NOEC\ \&\ EC10)}$ values for each organism group were then merged so that the lowest ACL$_{(NOEC\ \&\ EC10)}$ value for each combination of soil pH and CEC was adopted (Table 24). These should theoretically protect 99%, 80% and 60% of all soil processes, soil invertebrate species and plant species that are exposed to aged Zn contamination in soils that have a national park/area with high ecological value, urban residential/public open space, commercial/industrial land use, respectively.

Table 24. Soil-specific added contaminant limits based on no observed effect concentration and 10% effect concentration toxicity data (ACL$_{(NOEC\ \&\ EC10)}$, mg/kg) for aged zinc (Zn) contamination that should theoretically provide the appropriate level of protection (i.e., 99, 80 or 60% of species) to soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.0 to 7.5 and CEC values ranging from 5 to 60 cmol$_c$/kg. These are the recommended ACL$_{(NOEC\ \&\ EC10)}$ values for Zn in freshly contaminated soils with each land use.

National park/area with high ecological value land use						
pH	CEC (cmol$_c$/kg)					
	5	10	20	30	40	60
4.0	10	10	10	10	10	10
4.5	15	20	20	20	20	20
5.0	20	25	25	25	25	25
5.5	25	40	40	40	40	40
6.0	35	55	55	55	55	55
6.5	35	55	85	85	85	85
7.0	35	55	100	125	125	125
7.5	35	55	100	130	170	180
Urban residential/public open space land use						
pH	CEC (cmol$_c$/kg)					
	5	10	20	30	40	60
4.0	45	55	55	55	55	55
4.5	60	80	80	80	80	80
5.0	85	110	110	110	110	110
5.5	110	170	170	170	170	170
6.0	150	250	250	250	250	250
6.5	150	250	370	370	370	370
7.0	150	250	440	550	550	550
7.5	150	250	440	600	750	800

pH	CEC (cmol$_c$/kg)					
	5	10	20	30	40	60
4.0	70	85	85	85	85	85
4.5	100	120	120	120	120	120
5.0	125	180	180	180	180	180
5.5	180	270	270	270	270	270
6.0	230	400	400	400	400	400
6.5	230	400	590	590	590	590
7.0	230	400	690	870	870	870
7.5	230	400	690	940	1200	1300

3.7.2.2 Calculation of ambient background concentration values

The ABC values for aged Zn contamination used to calculate aged SQG(LOEC and EC30) and SQG(EC50) values were obtained from Olszowy et al. (1995) and are presented in Table 14.

3.7.2.3 Examples of soil quality guidelines for Australian soils with aged zinc contamination based on no observed effect concentration and 10% effect concentration data

SQGs are the sum of the ABC and ACL values, both of which are soil-specific. It is, therefore, not possible to present a single set of aged SQGs. Thus, some examples of aged SQGs for aged urban contaminated soils are provided below. The presented examples represent SQGs that would be at the low and high end of the range of SQGs that would be generated for Australian soils, but are not extreme values.

Example 1

Site descriptors – urban residential/public open space land use in an old NSW suburb with low traffic volume.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with 1% iron and aged Zn contamination

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:

$ACL_{(NOEC \& EC10)}$	110	mg/kg
ABC	75	mg/kg
$SQG_{(NOEC \& EC10)}$	185	mg/kg

Example 2

Site descriptors – commercial/industrial land use in an old Queensland suburb with a high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron and aged Zn contamination

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:

$ACL_{(NOEC \& EC10)}$	1200	mg/kg
ABC	160	mg/kg
$SQG_{(NOEC \& EC10)}$	1360	mg/kg

3.7.3 Calculation of soil quality guidelines for aged zinc contamination based on lowest observed effect concentration and 30% effect concentration toxicity data and based on 50% effect concentration toxicity data

3.7.3.1 Calculation of added contaminant limits for aged zinc contamination based on lowest observed effect concentration and 30% effect concentration and based on 50% effect concentration toxicity data

The Zn $SQG_{(LOEC \& EC30)}$ and $SQG_{(EC50)}$ values for aged sites were calculated using the method described in this Schedule with the exception that aged or age-corrected Zn toxicity data were used (Tables 21–23). Table 25 presents the $ACL_{(LOEC \& EC30)}$ and $ACL_{(EC50)}$ values for the Australian reference soil (Table 6) for National park/area with high ecological value, urban residential/public open space, and commercial/industrial land uses.

The soil-specific ACL$_{(LOEC\ and\ EC30)}$ and ACL$_{(EC50)}$ values for aged Zn contamination and the various land uses are presented in Tables 26 and 27 respectively. As with the ACL$_{(NOEC\ \&\ EC10)}$ values for aged Zn contamination, the ACL$_{(LOEC\ \&\ EC30)}$ and ACL$_{(EC50)}$ values must have the soil-specific ABC added. Therefore, the SQG$_{(LOEC\ \&\ EC30)}$ and SQG$_{(EC50)}$ values will be larger than the corresponding ACL values presented in Tables 26 and 27, respectively. Examples of the SQG$_{(LOEC\ \&\ EC30)}$ and SQG$_{(EC50)}$ values are provided below.

Table 25. Zinc (Zn) ACLs for the Australian reference soil (pH = 6, cation exchange capacity = 10 cmolc/kg) based on lowest observed effect concentration and 30% effect concentration toxicity data and based on 50% effect concentration toxicity data.

Land use	ACL$_{(LOEC\ \&\ EC30)}$ values (mg/kg added Zn)	ACL$_{(EC50)}$ values (mg/kg added Zn)
National park /area with high ecological value	90	140
Urban residential/public open space	400	700
Commercial/industrial	630	1100

Table 26. Soil-specific added contaminant limits based on lowest observed effect concentration and 30% effect concentration toxicity data (ACL$_{(LOEC\ \&\ EC30)}$, mg/kg) for aged zinc (Zn) contamination that should theoretically provide the appropriate level of protection (i.e., 99, 80 or 60% of species) to soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.0 to 7.5 and CEC values ranging from 5 to 60 cmol$_c$/kg. These are the recommended ACL$_{(LOEC\ \&\ EC30)}$ values for Zn in aged contaminated soils with each land use.

National park/area with high ecological value land use

pH	CEC (cmol$_c$/kg) 5	10	20	30	40	60
4.0	15	20	20	20	20	20
4.5	20	25	25	25	25	25
5.0	30	40	40	40	40	40
5.5	40	60	60	60	60	60
6.0	50	90	90	90	90	90
6.5	50	90	130	130	130	130
7.0	50	90	150	190	190	190
7.5	50	90	150	210	260	280

Urban residential/public open space land use

pH	CEC (cmol$_c$/kg) 5	10	20	30	40	60
4.0	70	85	85	85	85	85
4.5	100	120	120	120	120	120
5.0	130	180	180	180	180	180
5.5	180	270	270	270	270	270
6.0	230	400	400	400	400	400
6.5	230	400	590	590	590	590
7.0	230	400	700	880	880	880
7.5	230	400	700	960	1200	1300

Commercial/industrial land use						
pH	CEC ($cmol_c/kg$)					
	5	10	20	30	40	60
4.0	110	130	130	130	130	130
4.5	150	190	190	190	190	190
5.0	210	290	290	290	290	290
5.5	280	420	420	420	420	420
6.0	360	620	620	620	620	620
6.5	360	620	920	920	920	920
7.0	360	620	1100	1400	1400	1400
7.5	360	620	1100	1500	1900	2000

Table 27. Soil-specific added contaminant limits based on 50% effect concentration toxicity data ($ACL_{(EC50)}$, mg/kg) for aged zinc (Zn) contamination that should theoretically provide the appropriate level of protection (i.e., 99, 80 or 60% of species) to soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.0 to 7.5 and cation exchange capacity (CEC) values ranging from 5 to 60 $cmol_c$/kg. These are the recommended $ACL_{(EC50)}$ values for Zn in aged contaminated soils with each land use.

National park/area with high ecological value land use						
pH	CEC ($cmol_c/kg$)					
	5	10	20	30	40	60
4.0	25	30	30	30	30	30
4.5	35	45	45	45	45	45
5.0	45	65	65	65	65	65
5.5	65	95	95	95	95	95
6.0	85	140	140	140	140	140
6.5	85	140	210	210	210	210
7.0	85	140	250	310	310	310
7.5	85	140	250	340	430	460
Urban residential/public open space land use						
pH	CEC ($cmol_c/kg$)					
	5	10	20	30	40	60
4.0	130	150	150	150	150	150
4.5	170	220	220	220	220	220
5.0	230	330	330	330	330	330
5.5	320	480	480	480	480	480
6.0	410	710	710	710	710	710
6.5	410	710	1100	1100	1100	1100
7.0	410	710	1200	1600	1600	1600
7.5	410	710	1200	1700	2100	2300
Commercial/industrial land use						
pH	CEC ($cmol_c/kg$)					
	5	10	20	30	40	60
4.0	200	230	230	230	230	230
4.5	270	350	350	350	350	350
5.0	370	510	510	510	510	510
5.5	510	760	760	760	760	760
6.0	650	1100	1100	1100	1100	1100
6.5	650	1100	1700	1700	1700	1700
7.0	650	1100	1900	2500	2500	2500
7.5	650	1100	1900	2700	3400	3600

3.7.3.2 *Calculation of ambient background concentrations*

The ABC values used for aged Zn contamination are presented in Table 14.

3.7.3.3 *Examples of soil quality guidelines for Australian soils with aged zinc contamination based on lowest observed effect concentration and 30% effect concentration data and based on 50% effect concentration toxicity data*

Both the ACL and ABC values for aged zinc contamination are soil-specific therefore a single set of SQGs could not be presented. Thus, examples from the low and high portions of the range of SQG(LOEC & EC30) and SQG(EC50) are presented below.

$SQG_{(LOEC\ \&\ EC30)}$ - Example 1

Site descriptors - urban residential/public open space land use in an old NSW suburb with low traffic volume.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with 1% iron content.

The resulting $ACL_{(LOEC\ \&\ EC30)}$, ABC and $SQG_{(LOEC\ \&\ EC30)}$ values are:

$ACL_{(LOEC\ \&\ EC30)}$	180	mg/kg
ABC	75	mg/kg
$SQG_{(LOEC\ \&\ EC30)}$	255	mg/kg

This $SQG_{(LOEC\ \&\ EC30)}$ would then be rounded off using the rules in section 2.1 to a value of 250 mg/kg.

$SQG_{(LOEC\ \&\ EC30)}$ - Example 2

Site descriptors - commercial/industrial land use in an old Victorian suburb with high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(LOEC\ \&\ EC30)}$, ABC and $SQG_{(LOEC\ \&\ EC30)}$ values are:

$ACL_{(LOEC\ \&\ EC30)}$	1900	mg/kg
ABC	120	mg/kg
$SQG_{(LOEC\ \&\ EC30)}$	2020	mg/kg

This $SQG_{(LOEC\ \&\ EC30)}$ would then be rounded off using the rules in section 2.1 to a value of 2000 mg/kg.

$SQG_{(EC50)}$ - Example 3

Site descriptors - urban residential/public open space land use in an old NSW suburb with low traffic volume.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with 1% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$	330	mg/kg
ABC	75	mg/kg
$SQG_{(EC50)}$	405	mg/kg

This $SQG_{(EC50)}$ would then be rounded off using the rules in section 2.1 to a value of 400 mg/kg.

$SQG_{(EC50)}$ - Example 4

Site descriptors - commercial/industrial land use in an old Victorian suburb with high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$	3400	mg/kg
ABC	41	mg/kg
$SQG_{(EC50)}$	3441	mg/kg

This $SQG_{(EC50)}$ would then be rounded off using the rules in section 2.1 to a value of 3500 mg/kg.

3.8 Reliability of the zinc soil quality guidelines

Based on the criteria established in the methodology for SQG derivation (Schedule B5b) the Zn SQGs were considered to be of high reliability. This occurred as the toxicity data set easily met the minimum data requirements to use the SSD method and normalisation relationships were available to account for soil characteristics.

3.9 Comparison with other guidelines

A compilation of SQGs for Zn from a number of jurisdictions is presented in Table 28. These SQGs have a variety of purposes and levels of protection and therefore comparison of the SQGs amongst each other and with the Zn SQGs 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 superceded interim urban EIL (NEPC 1999a) was 200 mg/kg total Zn and therefore at the top of the range of the international Zn guidelines.

The Zn $ACL_{(NOEC \,\&\, EC10)}$ values in freshly contaminated urban residential/public open space soils ranged from 20 – 330 mg/kg (added Zn) (Table 10). The corresponding values for urban residential/public open space soils with aged Zn contamination ranged from 45 – 810 mg/kg (Table 24). The lowest ACLs (for sandy acidic soils) were very similar to the lowest of the international SQGs, but considerably lower than the superceded interim urban EIL. However, the largest ACLs (for neutral to alkaline, high CEC soils) were considerably larger than any of the international SQGs apart from the Dutch intervention level, which has a different purpose to the ACLs. Thus, in soils where the Zn has a low bioavailability, higher concentrations of Zn are permitted under the methodology than under the superceded interim urban EIL.

The intervention value in the Netherlands is 720 mg/kg total Zn. The range of $ACL_{(EC50)}$ values (which most closely relate to the Dutch intervention value) in freshly contaminated urban residential/public open space soils was 50 – 940 mg/kg (Table 20). While the range for aged Zn contamination was 125 – 2300 mg/kg (Table 27), the Dutch value corresponds to the 60^{th} and 25^{th} percentile of the range of $ACL_{(EC50)}$ values for fresh and aged Zn contamination respectively. Therefore, depending on soil physicochemical properties, the $ACL_{(EC50)}$ values would permit considerably less (in high bioavailability soils) to considerably more (in low bioavailability soils) Zn than in the Netherlands.

Table 28. Soil quality guidelines for zinc (Zn) from international jurisdictions.

Name of zinc limit	Numerical value of the limit (mg/kg)
Dutch intervention level[1]	720 (added Zn)
Dutch maximum permissible addition[1]	20 (added Zn)
Canadian SQG (residential)[2]	200 (total Zn)
Eco-SSL plants[3]	160 (total Zn)
Eco-SSL soil invertebrates[3]	120 (total Zn)
Eco-SSL avian[3]	46 (total Zn)
Eco-SSL mammalian[3]	79 (total Zn)
EU soil guidelines using negligible risk[4]	67-150 (total Zn)

1 = VROM, 2000
2 = CCME, 1999a and 2006 and http://www.ccme.ca/publications/list_publications.html#link2
3 = http://www.epa.gov/ecotox/ecossl/; 4 = Carlon, 2007

4 Arsenic

4.1 Arsenic compounds considered

The metalloid As occurs in a number of oxidation states: -3 (-III); 0, +3 (III); and +5 (V). As (III) is the dominant form under reducing conditions and As (V) is the dominant form in oxidised soils. The SQG derivation methodology (Schedule B5b) is only suitable for the aerobic portion of soils. SQGs for As were therefore calculated using only well oxidised soil studies. Therefore, arsenic will predominantly be present as As (V) however, as all the toxicity studies expressed toxicity in terms total arsenic the SQGs generated in this study are for total arsenic. For waterlogged soils, a separate As SQG should be derived due to the difference between As (III) and As (V) in both toxicity and bioavailability in these soils. The chemical abstract service number (a unique identification number for each chemical) for As is 7440-38-2.

4.2 Exposure pathway assessment

The two key considerations in determining the most important exposure pathways for inorganic contaminants, such as As, are whether they biomagnify and whether they have the potential to leach to groundwater. A surrogate measure of the potential for a contaminant to leach is its water to soil partition coefficient (Kd). If the logarithm of the Kd (log Kd) of an inorganic contaminant is less than three then it is considered to have the potential to leach to groundwater (Schedule B5b). The log Kd reported by Crommentuijn et al. (2000) was 2.28 L/kg, therefore As has the potential in some soils to leach to groundwater. This is consistent with human health problems experienced in Bangladesh from the presence of As in groundwater. The methodology for EIL derivation (Schedule B5b) does not advocate the routine derivation of EILs that account for leaching potential. Rather, it advocates that this is done on a site-specific basis as appropriate. However, the calculations are presented here to illustrate the recommended approach and the effect that this would have on the resulting SQGs.

Arsenic is not known to biomagnify in oxidised soils (Heemsbergen et al. 2009) and therefore only direct toxicity routes of exposure were considered in deriving the SQGs.

4.3 Toxicity data

The raw toxicity data for As are presented in Appendix B. The toxicity data (geometric means for each species) used to calculate the SQGs are presented in Table 29. There were toxicity data for three soil invertebrate species, five terrestrial animal species and 13 species of plants. These meet the minimum data requirements recommended by Heemsbergen et al. (2008) to use the BurrliOZ SSD method (Campbell et al. 2000).

Table 29. Geometric mean values of arsenic (As) toxicity data (expressed in terms of total As) for soil invertebrate species, terrestrial bird and mammal species and plant species.

Test species		Geometric mean (mg/kg)		
Common name	**Scientific name**	**EC10 or NOEC**	**EC30 or LOEC**	**EC50**
Bean	*Phaseolus vulgaris*	22.6	84	168
Blueberry	*Vaccinium sp.*	22.2	55	111
Common rat	*Rattus norvegicus*	10.0	25	50
Corn	*Z. mays*	25.1	67	123
Cotton	*Gossypium sp.*	20.8	52	104
Deer mouse	*Peromyscus maniculatus*	320	1600	1600
Earthworm	*E. fetida*	20.0	100	100
Earthworm	*L. rubellus*	76.1	381	381
Earthworm	*L. terrestris*	100	250	500
Fulvous whistling duck	*Dendrocygna bicolour*	229	1145	1145
Grass		13.4	81	161
Northern bobwhite	*Colinus virginianus*	54.0	270	270
Oat	*A. sativa*	22.7	44	70
Pea	*Pisum sativum*	20.8	52	104
Pine		292	731	1462
Potato	*Solanum tuberosum*	36.3	108	181
Radish	*Raphanus sativa*	67.7	169	339
Sheep	*Ovis aries*	25.0	63	125
Soyabean	*Glycine max*	9.7	24	35
Tomato	*L. esculentum*	62.5	166	263
Wheat	*T. aestivum*	43.4	153	307

In order to maximise the use of the available toxicity data, conversion factors (adopted from the *Australian and New Zealand guidelines for fresh and marine water quality* (ANZECC & ARMCANZ 2000) by Heemsbergen et al. (2008)) were used to permit the inter-conversion of NOEC, LOEC, EC50, EC30 and EC10 data. Conversion factors for cations (for example, Cu and Zn) were developed by the NBRP and recommended by Heemsbergen et al. (2008) in preference to the default conversion factors adopted from the WQGs. However, as As is predominantly found in anionic form in soils, the default conversion factors were used (Table 30).

Table 30. The default conversion factors used to convert different measures of toxicity to chronic no observed effect concentrations (NOECs) or 10% effect concentrations (EC10). Sourced from Heemsbergen et al. (2008) who adopted the values from the Australian and New Zealand guidelines for fresh and marine water quality (ANZECC & ARMCANZ, 2000).

Toxicity data[a]	Conversion factor
EC50[b] to NOEC or EC10	5
LOEC or EC30 to NOEC or EC10	2.5
MATC* to NOEC or EC10	2

[a] EC50 is the concentration that causes a 50% effect, EC30 is the concentration that causes a 30% effect, EC10 is the concentration that causes a 10% effect, NOEC = 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.

4.4 Normalisation relationships

It is well known that soil physicochemical properties affect the toxicity and bioavailabiity of As. However, this knowledge is qualitative. For example, Sheppard (1992) reviewed the existing literature and concluded that the toxicity of As was five times more toxic in sands and loams than in clay soils. There is only one set of published normalisation relationships for As toxicity (Song et al. 2006). This relates the toxicity of As (i.e. barley root elongation) expressed in terms of total added As, ammonium sulphate [$(NH_4)_2SO_4$]-extractable As or ammonium phosphate ($NH_4H_2PO_4$)-extractable As to soil properties such as oxalate-extractable Mn and oxalate-extractable Fe concentrations. The normalisation relationships for EC10 and EC50 toxicity data expressed in terms of total added As (from Song et al. 2006) are:

EC10 = 0.1 (oxalate-extractable Mn) + 1.03 (% clay) – 9.25 *(equation 3)*
(r^2 adj = 0.89, p = < 0.001, n = 16)

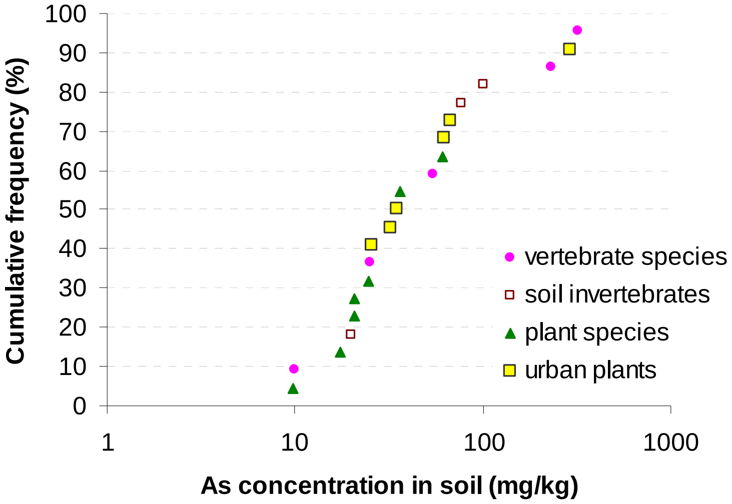
EC50 = 0.21 (oxalate-extractable Mn) + 0.016 (oxalate-extractable Fe) *(equation 4)*
+ 4.29 (% clay) – 48.2
(r^2 adj = 0.91, p = < 0.001, n = 16)

However, with the exception of the Song et al. (2006) data none of the available As toxicity had expressed the toxicity in the units of the normalisation relationships nor had the studies measured the soil properties used in the normalisation relationships. Therefore, the normalisation relationships could not be used.

4.5 Sensitivity of organisms to arsenic

Figure 4 shows the SSD (that is, the cumulative distribution of the geometric means of species' sensitivities to As) for all species for which As toxicity data were available. The distribution of the major groups of organisms along the SSD is uniform – thus all of the organism groups have a smilar sensitivity to As.

Figure 4. The species sensitivity distribution (plotted as a cumulative frequency against total arsenic (As) concentration) of As for soil invertebrate species, terrestrial vertebrate species and plant species.



4.6 Calculation of soil quality guidelines for fresh arsenic contamination

The As toxicity data could not be normalised to the Australian reference soil because none of the publications had reported the properties required by the one normalisation relationship available for As. Thus, soil-specific ACLs could not be derived. Rather, a single generic ACL for each land use was derived. These generic ACLs would apply to all Australian soils of the appropriate land use. For example, the single ACL for urban residential /public open space land use would apply to all Australian urban residential/public open space soils.

4.6.1 Calculation of soil quality guidelines for fresh arsenic contamination based on no observed effect concentration and 10% effect concentration toxicity data

All the available As toxicity data (apart from that of Song et al. 2006) were reported as total concentrations without making a distinction between added and background concentrations. The Hamon et al. (2004) method can predict the ABC for As in Australian soils. For European soils or toxicity studies, the Dutch background standardisation equation for As can be used (Lexmond et al. 1986):

As= 0.4*(clay content + organic matter content) *(equation 5)*

However, the As toxicity studies did not report the Fe and Mn contents (required by the Hamon et al., 2004 method) or the organic matter or clay content (required by the Lexmon et al. 1986 method) of the soils in which the toxicity was determined. Therefore, it was not possible to estimate the ABC nor express toxicity in terms of added concentrations. As a result, no ACL values could be calculated.

The situation for As was that:

- there were sufficient toxicity data to use the BurrliOZ software
- the data could not be normalised to the Australian reference soil
- the toxicity data could not be expressed in terms of added concentrations
- a background concentration for As could not be calculated.

Therefore, only a single numerical value was generated by the BurrliOZ SSD method for each of the three land uses (that is, national park/area with high ecological value, urban residential/public open space, and commercial/industrial).

The output was the $SQG_{(NOEC \& EC10)}$ for that particular land use and no soil-specific $SQG_{(NOEC \& EC10)}$ values could be calculated. The As $SQG_{(NOEC \& EC10)}$ values for the three land uses are presented in Table 31.

Table 31. generic soil quality guidelines based on no observed effect concentration and 10% effect concentration toxicity data ($SQG_{(NOEC \& EC10)}$) for fresh arsenic (As) contamination in soil with different land uses.

Land use	$SQG_{(NOEC \& EC10)}$ (mg/kg total As)
National park /area with high ecological value	8
Urban residential/public open space	20
Commercial/industrial	30

It should be noted, because As has generic $SQG_{(NOEC \& EC10)}$ values, that they should be applied to all Australian soils that have the particular land use.

4.6.1.1 Calculation of ambient background concentration values

Despite the fact that ACLs could not be derived for As, the issue of background concentrations of As in Australian soils will be discussed as the situation could change in the future if additional data becomes available. If, in the future, toxicity data can be expressed in terms of added concentrations, it is recommended that the method of Hamon et al. (2004) be used to derive ABC values. Examples of the ABC values generated by the Hamon et al. (2004) method are presented in Table 32. The soil-specific estimate of ABC could be added to a generic ACL (if toxicity data could be expressed as added As, but no normalisation relationships were suitable) or it could be added to a soil-specific ACL (if it were possible to express the toxicity data in terms of added As and if normalisation relationships could be applied to the data).

Table 32.Ambient background conventrations of arsenic (As) estimated using the method of Hamon et al. (2004) as a function of the iron content of the soil.

Soil iron (%)	As (mg/kg)
0.1	1
1	3
10	12
20	18

4.6.2 Calculation of soil quality guidelines for fresh arsenic contamination based on protecting aquatic ecosystems from leaching

The log Kd value for As (Crommentuijn et al. 2000) was below 3 and therefore in accordance with the SQG derivation methodology (Schedule B5b) $SQG_{(NOEC \& EC10)}$ values were derived to protect aquatic ecosystems from the effects of leached As from freshly contaminated soils.

The As $SQG_{(NOEC \& EC10)}$ values based on protecting groundwater ecosystems were calculated using the US EPA method (US EPA 1996). The generic $SQG_{(NOEC \& EC10)}$ values were calculated using DAF values of one and 20 and these are presented in Table 33. There is a linear relationship between the DAF and the SQGs, thus the SQGs calculated using a DAF of 20 are 20 times larger than those calculated using a DAF of 1.

Table 33. Generic arsenic (As) soil quality guidelines (SQGs, mg total As/kg) based on no observed effect concentration and 10% effect concentration toxicity data to protect groundwater ecosystems from leaching.

Dilution factor	1	20
SQG (mg/kg)	4.6	91

4.6.3 Calculation of soil quality guidelines for fresh arsenic contamination based on lowest observed effect concentration and 30% effect concentration toxicity data and based on 50% effect concentration toxicity data

The $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values were calculated using the same method as that for the As $SQG_{(NOEC\ \&\ EC10)}$ values except that different toxicity data were used. The data used are presented in Table 29. To maximise the data available to generate the $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values, the available toxicity data were converted to the appropriate measure of toxicity using the default conversion factors presented in Table 30.

As with the $SQG_{(NOEC\ \&\ EC10)}$ values for As, soil-specific $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values could not be generated, rather a single generic $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ value were generated for each of the three land uses (Table 34). Also all toxicity data were expressed as total As rather than added As. As these are generic $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values they should be applied to all Australian soils with a particular land use.

Table 34: generic soil quality guidelines based on lowest observed effect concentration and 30% effect concentration toxicity data ($SQG_{(LOEC\ \&\ EC30)}$)and based on 50% effect concentration toxicity data ($SQG_{(EC50)}$) for soil with different land uses.

Land use	$SQG_{(LOEC\ \&\ EC30)}$ (mg/kg total As)	$SQG_{(EC50)}$ (mg/kg total As)
National park/area with high ecological value	20	30
Urban residential/public open space	50	90
Commercial/industrial	80	140

4.7 Calculation of soil quality guidelines for aged arsenic contamination

4.7.1 Calculation of an ageing and leaching factor for arsenic

Song et al. (2006) conducted some experiments to determine the effect of ageing As over three months in four soils. They found that in all soils the toxicity and extractability decreased however, the extent of the decrease ranged from 2- to 12-fold (Song et al. 2006). Yang et al. (2002) and Fendorf et al. (2004) also found that As aged in soils with the majority happening within the first few months. 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. Song et al. (2006) found that the extent of ageing was significantly correlated with oxalate-extractable iron and Olsen-P concentrations in the four test soils. However, they also noted that data on more soils were needed in order for the relationships to be more robust. Song et al. (2006) concluded that ageing of As 'should be taken into account during risk assessment'. Therefore, in order to account for ageing in a conservative manner (that is, one that is protective of the environment), the lowest ALF factor determined by Song et al. (2006) of two was used to derive the aged SQGs. This ALF was applied to all the toxicity data.

4.7.2 Calculation of soil quality guidelines for aged arsenic contamination

As the available toxicity data can only be expressed as totals As concentrations, ACL values could not be derived, rather, SQGs were derived. The ALF of two was applied to all the toxicity data therefore the aged $SQG_{(NOEC\ \&\ EC10)}$, $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values are exactly twice the corresponding fresh SQGs for arsenic. The resulting aged $SQG_{(NOEC\ \&\ EC10)}$, $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values are presented in Table 35.

Table 35. Generic soil quality guidelines based on no observed effect concentration and 10% effect concentration toxicity data ($SQG_{(NOEC\ \&\ EC10)}$), lowest observed effect concentration and 30% effect concentration toxicity data ($SQG_{(LOEC\ \&\ EC30)}$) and based on 50% effect concentration toxicity data ($SQG_{(EC50)}$) for soil with different land uses.

Land use	$SQG_{(NOEC\ \&\ EC50)}$ (mg/kg total As)	$SQG_{(LOEC\ \&\ EC30)}$ (mg/kg total As)	$SQG_{(EC50)}$ (mg/kg total As)
National park/area with high ecological value	15	40	60
Urban residential/public open space	40	100	180
Commercial/industrial	60	160	290

4.7.3 Calculation of ambient background concentration values

Background levels of As are not elevated by historic pollution in urban residential/public open space soils as can be seen by data from Olszowy et al. (1995) (Table 36). Therefore, in the future, if toxicity data can be expressed in terms of added concentrations, it is recommended that the method of Hamon et al. (2004) be used to estimate background values as they are soil-specific. Examples of the ABC values generated by the Hamon et al. (2004) method are presented in Table 32.

Table 36. Background concentrations of arsenic (As) from Olszowy et al. (1995) in suburbs of different age and with different intensities of traffic in various states of Australia.

Suburb type	25th percentile As (mg/kg)			
	NSW	QLD	SA	VIC
New suburb low traffic	5	3	5	NA
New suburb high traffic	5	3	5	NA
Old suburb low traffic	5	4	5	5
Old suburb high traffic	5	3	5	5

NA = not available

4.8 Reliability of the soil quality guidelines

The As toxicity dataset met the minimum data requirements to use the SSD method but there were no normalisation relationships available to account for soil characteristics. Based on the criteria for assessing the reliability of SQGs (Schedule B5b), this means that the As SQGs were considered to be of moderate reliability.

4.9 Comparison with other guidelines

A compilation of SQGs for As from a number of jurisdictions is presented in Table 37. These guidelines have a variety of purposes and levels of protection and therefore comparison of the values is problematic. The SQGs for As range from 4.5 mg/kg (added As) for the Dutch to 110 mg/kg (total As) for another European country. The superceded interim urban EIL (NEPC, 1999a) was 20 mg/kg total As and lies in the lower portion of the range of As SQGs. The As $SQG_{(NOEC \& EC10)}$ for freshly contaminated urban residential/public open space soils was 20 mg/kg (total As) and thus identical to the superceded interim urban EIL. The $SQG_{(NOEC \& EC10)}$ for aged contamination at 40 mg/kg is twice the superceded interim urban EIL for As.

The $SQG_{(LOEC \& EC30)}$ and $SQG_{(EC50)}$ values for As in freshly contaminated urban residential/public open space soils are 50 and 80 mg/kg respectively. The $SQG_{(LOEC \& EC30)}$ is in the middle of the range of SQGs for other jurisdictions, while the $SQG_{(EC50)}$ is in the upper portion of the range of SQGs. The aged As $SQG_{(LOEC \& EC30)}$ for urban residential/public open space soils lies in the upper part of the range of international SQGs while the aged As $SQG_{(EC50)}$ value for urban residential/public open space soils is markedly larger than any other international SQG.

Table 37. Soil quality guidelines for arsenic (As) from international jurisdictions.

Name of arsenic soil quality guideline	Numerical value of the guidelines (mg/kg)
Dutch target value[1]	29 (total As)
Dutch maximum permissible addition[1]	4.5 (added As)
Canadian SQG[2]	12 (total As)
Eco-SSL plants[3]	18 (total As)
Eco-SSL soil invertebrates[3]	NA
Eco-SSL avian[3]	43 (total As)
Eco-SSL mammalian[3]	46 (total As)
EU screening values potential risk in residential areas[4]	5 – 110 (total As)

1 = VROM, 2000
2 = CCME, 1999b, and 2006 and http://www.ccme.ca/publications/list_publications.html#link2
3 = http://www.epa.gov/ecotox/ecossl/
4 = Carlon, 2007
NA = not available

5 Naphthalene

5.1 Compounds considered

Unlike Zn and As, which can occur in several forms in soil, naphthalene is a unique compound and only information relating to it was used in the derivation of the SQG values. Naphthalene ($C_{10}H_8$) is the smallest of the family of compounds collectively termed polycyclic aromatic hydrocarbons (PAHs). The chemical abstract service number for naphthalene is 91-20-3 (HSDB 2004).

5.2 Exposure pathway assessment

Selected physicochemical properties of naphthalene are:

Molecular weight:	128.17 (O'Neil 2001)
Log Kow	3.29 (US EPA 1982), 3.01 – 3.45 (Verschueren 1983), 3.30 (Hansch et al., 1995)
Log Koc	2.97 (US EPA1982; GDCH 1992; Kenaga 1980)
Vapour pressure	0.087 mm Hg (US EPA 1982) 0.085 mm Hg at 25°C (Ambrose et al. 1975)
Aqueous solubility	31 mg/L at 25°C (Pearlman et al. 1984)
Henry's law constant	4.6 x 10^{-4} atm-m^3/mol (US EPA 1982; Yaws et al. 1991), 4.4 x 10^{-4} atm-m^3/mol (Shiu & Mackay 1997)
Half-life (in soil)	2 – 18 days (ATSDR 1995)

The minimum log Kow value at which biomagnification should be considered in the derivation of SQGs is 4 (Schedule B5b). As the reported log Kow values for naphthalene were below 4 and it has a relatively short half-life (see above), it is not considered a biomagnifying compound and the normal protection levels were used. Therefore only the direct toxicity exposure route was considered in the derivation of SQGs for naphthalene. The log Koc value for naphthalene is moderate (~ 3) and therefore there is only a moderate potential for naphthalene to be leached to groundwater or surface water. Soil quality guidelines to protect aquatic ecosystems were therefore not generated.

5.3 Toxicity data

Toxicity data for naphthalene were available for two plant species, eight species of soil invertebrates and four species of terrestrial vertebrates (Table 38). In total, there were data for 14 species that belonged to five taxonomic groups and thus this met the minimum data requirements recommended by the methodology to use the BurrliOZ SSD method (Campbell et al. 2000). Table 38 shows the geometric means of individual species used to derive the naphthalene SQGs. The raw toxicity data used to generate the species geometric means are presented in Appendix E.

In order to maximise the use of the available toxicity data, default conversion factors were used to permit the inter-conversion of NOEC, LOEC, EC50, EC30 and EC10 data (Table 30).

Table 38. Geometric means of the toxicity of naphthalene (expressed in terms of total naphthalene) to soil invertebrates, terrestrial vertebrates and plants.

Test species		Geometric mean (mg/kg)		
Common name	**Scientific name**	**NOEC or EC10**	**LOEC or EC30**	**EC50**
Earthworm	*E. fetida*	54	135	270
European rabbit	*Oryctolagus cuniculus*	2000	5000	10000
House mouse	*Mus musculus*	407	1018	2036
Lettuce	*L. sativa*	21	54	107
Mite	*Acari spp*	232	580	1160
Mite	*Mesostigmata spp.*	195	487	973
Mite	*Oribatida sp.*	219	547	1094
Northern bobwhite	*C. virginianus*	1000	2500	5000
Common rat	*R. norvegicus*	1000	2500	5000
Radish	*R. sativa*	61	153	305
Spider	*Grammonata inornata*	177	443	886
Springtail	*Collembola spp.*	214	535	1070
Springtail	*F. fimetaria*	20	50	100
Springtail	*Poduromorpha spp.*	203	508	1016

5.4 Normalisation relationships

It is well known that the organic carbon (OC) or organic matter content of soils affects the toxicity and bioavailabiity of organic contaminants such as naphthalene. European guidelines use normalisation relationships for organic contaminants (ECB 2003), but these have not yet been verified for Australian soils. In fact, when data for soils with OC contents greater than typical Australian soils were removed, OC was no longer a useful descriptor of toxicity (Broos et al. 2007). While the above example is for an inorganic contaminant, it shows the potential for European normalisation relationships to be inappropriate for Australia. As Australian soils are in general low in organic carbon, it was not recommended to use European normalisationships (Schedule B5b). There were no normalisation relationships available for naphthalene. Therefore, the toxicity data could not be normalised to the Australian reference soil, nor could soil-specific SQGs be derived.

5.5 Sensitivity of organisms to naphthalene

The SSD for the naphthalene toxicity data is presented in Figure 5. As there were only toxicity data for 14 different species, insufficient data were available to make a robust assessment of the relative sensitivity of the groups of organisms. Nonetheless, it appears that plant and soil invertebrate species were more sensitive to naphthalene than vertebrate species as the vertebrate toxicity data were all higher than those for other species. An argument could be mounted to exclude the terrestrial vertebrates from the calculation of the SQGs; however, this was not adopted for three reasons. Firstly, the data were sparse and therefore the differences in the relative sensitivity of the groups of organisms may not be real. Secondly, the terrestrial vertebrates represent a major group of organisms that we believe most people would wish to be able to maintain in urban residential/public open space settings. Thirdly, removal of these species only had a minor effect on the resulting $SQG_{(NOEC\ \&\ EC10)}$ (i.e. the PC80 for all species was 68 mg/kg while the corresponding value when the vertebrates were removed was 60 mg/kg).

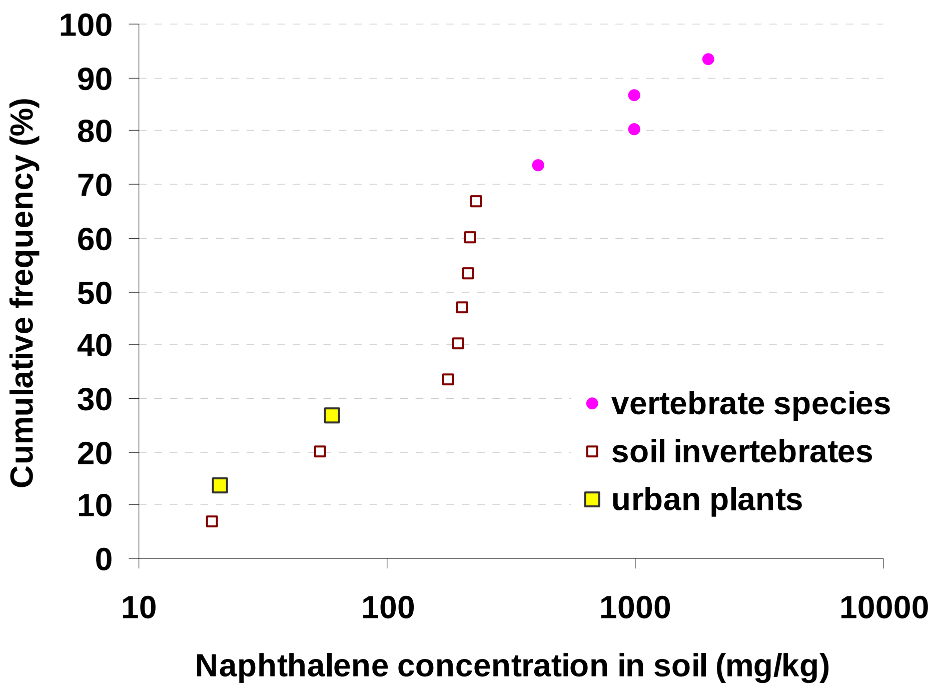


Figure 5. The species sensitivity distribution (plotted as a cumulative frequency of the toxicity data against naphthalene soil concentration) soil invertebrates, plants and terrestrial vertebrates to naphthalene.

5.6 Calculation of soil quality guidelines for fresh naphthalene contamination

Given that (a) there were sufficient toxicity data to use the BurrliOZ software, (b) the data could not be normalised to the Australian reference soil, and (c) the toxicity data could not be expressed in terms of added concentrations, it meant that there was a single output from the BurrliOZ SSD for each of the three land uses (that is, national park/area with high ecological value, urban residential/public open space, and commercial/industrial). Therefore, the output from the SSD was a single generic (not soil-specific) SQG for each land use.

5.6.1 Calculation of soil quality guidelines for fresh naphthalene contamination based on no observed effect concentration and 10% effect concentration toxicity data

The generic SQGs for naphthalene in soils with each of the three land uses are presented in Table 39.

Table 39. Generic soil quality guidelines for naphthalene in freshly contaminated soils with different land uses based on no observed effect concentration and 10% effect concentration toxicity data.

Land use	$SQG_{(NOEC\ \&\ EC10)}$ (mg/kg total naphthalene)
National park/area with high ecological value	5
Urban residential/public open space	70
Commercial/industrial	150

5.6.1.1 *Calculation of ambient background concentration values*

There is no equation available to estimate the background concentration of naphthalene. Naphthalene is produced by some organisms (for example, magnolias and termites) but at very low concentrations which are negligible in terms of ABC values. Naphthalene can also be synthesised as a result of fires and in fire prone areas and it might be appropriate to determine naphthalene ABC values. In most soils, naturally occurring naphthalene concentrations will be negligible. For the purpose of this guideline the ABC for naphthalene was assumed to be 0 mg/kg. Therefore, the reported toxicity values which were expressed as total naphthalene were identical to the data when expressed as added naphthalene concentrations (that is, total concentration – 0 = added concentration) and therefore the ACLs derived using the SSD methodology equalled the SQGs.

It should be noted that if a soil-specific ABC for naphthalene is determined then that could be added to the above values to obtain a soil-specific SQG. Otherwise, these generic SQGs are applicable to all Australian soils with these particular land uses.

5.6.2 Calculation of soil quality guidelines for fresh naphthalene contamination based on lowest observed effect concentration and 30% effect concentration data and based on 50% effect concentration toxicity data

These SQGs were calculated using the same method as that for the $SQG_{(NOEC \& EC10)}$ values for naphthalene, except that different toxicity data were used (Table 38). To maximise the data available to generate $SQG_{(LOEC \& EC30)}$ and $SQG_{(EC50)}$ values, the available toxicity data were converted to the appropriate measure of toxicity using the default conversion factors recommended in Schedule B5b and presented in Table 30.

As with the $SQG_{(NOEC \& EC10)}$ values for naphthalene, soil-specific $ACL_{(LOEC \& EC30)}$ and $ACL_{(EC50)}$ values could not be generated, rather a single generic $SQG_{(LOEC \& EC30)}$ and $SQG_{(EC50)}$ were generated for each of the three land uses (Table 40). It should be noted that if a soil-specific ABC for naphthalene is determined then that could be added to the generic SQG values (Table 40) to obtain a soil-specific SQG. Otherwise these generic $SQG_{(LOEC \& EC30)}$ and $SQG_{(EC50)}$ values should apply to all Australian soils with these particular land uses.

Table 40. Generic soil quality guidelines for naphthalene in freshly contaminated soil with different land uses based on lowest observed effect concentration and 30% effect concentration toxicity data and based on 50% effect concentration toxicity data.

Land use	$SQG_{(LOEC \& EC30)}$ (mg/kg total naphthalene)	$SQG_{(EC50)}$ (mg/kg total naphthalene)
National park/area with high ecological value	10	25
Urban residential/public open space	170	340
Commercial/industrial	370	730

5.7 Calculation of soil quality guidelines for aged naphthalene contamination

There is currently no ageing or leaching factor available for naphthalene in the literature and therefore SQGs for aged contamination could not be derived.

5.8 Metabolites of naphthalene

The most well known metabolites of naphthalene are 1-naphthol (CAS no. 90-15-3) or 2-naphthol (CAS no. 135-19-3). These compounds are both known to affect plant growth and are suspected to have endocrine disrupting properties (Pesticide Action Network at <www.pesticideinfo.org>). There are no toxicity data in soils or SQGs reported for these compounds.

5.9 Reliability of the soil quality guidelines

The naphthalene toxicity dataset met the minimum data requirements to use the SSD method but there were no normalisation relationships available to account for soil characteristics. Based on the criteria for assessing the reliability of SQGs (Schedule B5b), the naphthalene SQGs were considered to be of moderate reliability.

5.10 Comparison with other guidelines

A compilation of SQGs for naphthalene in a number of jurisdictions is presented in Table 41. These SQGs have a variety of purposes and levels of protection and therefore comparison of the values is problematic. The SQGs for naphthalene range from 0.6 mg/kg for Canada to 125 mg/kg for the USA, both expressed as total naphthalene. The NEPM (NEPC 1999a) did not include an EIL for naphthalene. The SQG$_{(NOEC \,\&\, EC10)}$ for national parks/areas with high ecological value freshly contaminated with naphthalene is 5 mg/kg and thus this is identical to the lower range of values set within the EU, but approximately an order of magnitude higher than the Canadian SQG and 1/25th of the USA SQG. The SQG$_{(NOEC \,\&\, EC10)}$ for urban residential/public open space is 70 mg/kg and thus slightly higher than the highest EU SQGs but still approximately half the US EPA screening level for residential land. The SQG$_{(LOEC \,\&\, EC30)}$ for urban residential land use at 170 is 40% larger than the US EPA screening level, while the corresponding SQG$_{(EC50)}$ value is approximately 2.8 times the US EPA screening level.

Table 41. Soil quality guidelines for naphthalene in a number of jurisdictions.

Name of the naphthalene soil quality guideline	Value of the guidelines (mg/kg)
Canadian SQG (residential)[1]	0.6
EU (residential)[2]	5-60
US EPA Screening level (residential)[3]	125

1 = CCME 1999c , 2006 and <http://www.ccme.ca/publications/list_publications.html#link2>
2 = Carlon 2007
3 = <http://www.epa.gov/ecotox/ecossl/>.

6 DDT

6.1 Compounds considered

DDT is the abbreviation used for dichloro-diphenyl-trichloroethane ($C_{14}H_9Cl_5$). Technical grade DDT (the form used in pesticide formulations) consists of 14 compounds (ATSDR 2002). The active ingredient and the main constituent of DDT is p,p′-DDT (approx 87% of DDT). Other compounds present include o,p′-DDT (15% of DDT), dichloro-diphenyl-dichloroethylene (DDE) and dichloro-diphenyl-dichloroethane (DDD) which are also metabolites and breakdown products of DDT. When DDT is referred to, usually people are referring to p,p′-DDT and this was the form that was used for the derivation of the EIL. The CAS registration number for p,p'-DDT is 50-29-3.

6.2 Pathway risk assessment

Selected physicochemical properties of DDT include:

Molecular weight	354.49 (Howard & Meylan 1997)
Log Kow	6.91 (Howard & Meylan 1997; Hansch et al. 1995)
Log Koc	5.18 (Swann et al. 1981)
Vapor pressure	1.60×10^{-7} at 20 ^{o}C (Bidleman & Foreman 1987)
Aqueous solubility	0.025 mg/L at 25^{o}C (Howard & Meylan 1997),
	5.5 x 10-3 mg/L at 25^{o}C (Yalkowsky & Dannenfelser 1992)
Henry's law constant	8.3 x 10-6 atm-m^3/mol (Howard & Meylan 1997)
Half-life (in aerobic soil)	range from 2 years (Lichenstein & Schulz 1959) to greater than 15 years (Keller 1970; Stewart & Chisholm 1971)
Half-life (in anaerobic soil)	16 – 100 days (Castro & Yoshida 1971)
Half-life of DDT	190 years (OMEE 1993)
Bioconcentration factor	2.5 to 16 (CCME 1999d)
Bioaccumulation factor	0.9 to 29 (CCME 1999d)

DDT is a well known biomagnifying contaminant and, as the log Kow is higher than 4, both the direct toxicity and biomagnification routes of exposure needed to be accounted for in deriving the SQGs. Therefore, the level of protection (that is, percentage of species to be protected) was increased for urban residential/public open space soils from 80% to 85% as recommended in Schedule B5b. The log Koc value for DDT is >5 and therefore there is a very low potential for DDT to be leached to groundwater or surface water.

6.3 Toxicity data

The raw toxicity data available for DDT are presented in Appendix F. The geometric means of toxicity data for each species and soil process are presented in Table 42. There were toxicity data for a total of 15 species or soil processes that belong to 5 different taxonomic groups or nutrient groups. Thus, there were sufficient toxicity data to use the SSD method to derive SQGs for DDT.

6.4 Normalisation relationships

As with naphthalene, it is well known that the organic carbon or organic matter content of soils affects the toxicity and bioavailabiity of organic contaminants such as DDT. However, there were no normalisation relationships available for DDT. Therefore, the toxicity data could not be normalised to the Australian reference soil (Table 6), nor could soil-specific SQGs be derived.

6.5 Sensitivity of organisms to DDT

Figure 6 shows the SSD (that is, the cumulative distribution of the geometric means of toxicity values) for the species used to derive the DDT SQGs. There is a general paucity of terrestrial toxicity data for DDT. This is particularly the case for plants and soil invertebrates where each group only has data for two species. It is therefore difficult to assess the relative sensitivity of these groups of organisms. Soil processes had sensitivities to DDT ranging from very sensitive to very tolerant, although most were in the more tolerant part of the distribution. Both plants were tolerant of DDT. Both soil invertebrates had moderate sensitivity while the vertebrate species were generally sensitive. The greater sensitivity of the vertebrates is consistent with the findings on the relative sensitivity of aquatic species.

Table 42. The geometric mean values of the DDT toxicity data for soil invertebrate species, terrestrial vertebrate species, plant species and soil processes.

Test species		Geometric means (mg/kg)		
Common name	**Scientific name**	**NOEC or EC10**	**LOEC or EC30**	**EC50**
Earthworm	*E. fetida*	363	1131	2499
Field mustard	*Brassica rapa*	1000	2500	5000
Helmeted guineafowl	*Numida meleagris*	30	75	150
House sparrow	*Passer domesticus*	600	1500	3000
Japanese quail	*Coturnix japonica*	80	200	400
Mallard duck	*Anas platyrhynchos*	24	59	119
Northern bobwhite	*C. virginianus*	68	170	341
Oats	*A. sativa*	1000	2500	5000
Ring-necked pheasant	*Phasianus colchicus*	104	261	522
Soil process	Ammonification	1250	3125	6250
Soil process	Nitrification	56	141	281
Soil process	Respiration	1000	2500	5000
Soil process	SIN	1000	2500	5000
Soil process	SIR	1000	2500	5000
Springtail	*F. candida*	464	1344	2836

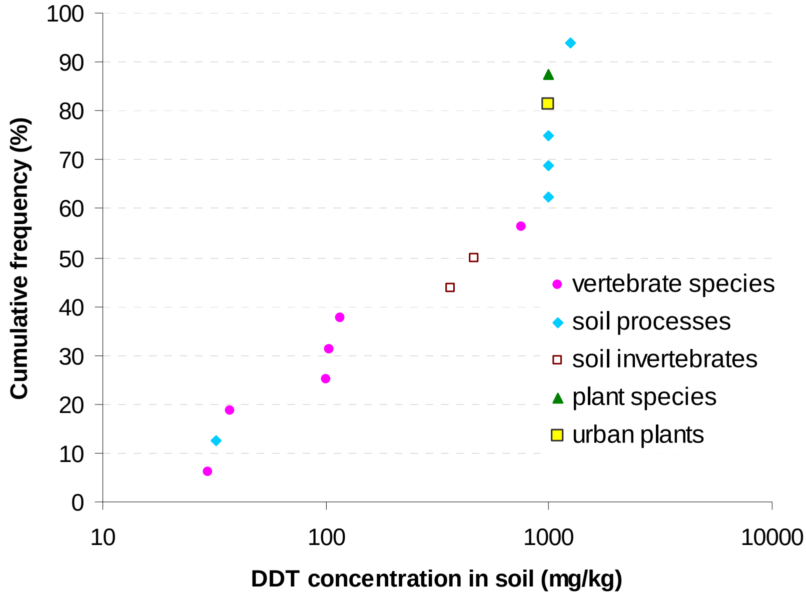


Figure 6. The species sensitivity distribution (plotted as a cumulative frequency of the toxicity data against DDT soil concentration) of soil invertebrate species, soil processes, plant species and terrestrial vertebrate species to DDT.

6.6 Calculation of soil quality guidelines for fresh DDT contamination

All the available DDT toxicity data were reported as total concentrations without making a distinction between added and background concentrations. There was no equation available able to estimate the background concentration of DDT. DDT only occurs due to its synthesis by humans. There is therefore no 'natural' background concentration of DDT. However, due to its persistence and its ability to volatilise, DDT can be subject to long-distance transport. In fact, a global distillation hypothesis was developed and has widely been accepted as the explanation of the presence of DDT, and its metabolites and other persistent organic pollutants in polar ecosystems which have no nearby industrial point sources or non-point sources. Because of this global transport of DDT, it could be argued that there is an ABC. As the DDT toxicity studies did not provide any estimate of the ABC for DDT either at the sites or in the soils that were used, this could not be accounted for in deriving the limits for DDT. Therefore, a default ABC for DDT of 0 mg/kg was adopted.

6.6.1 Calculation of generic soil quality guidelines for fresh DDT contamination based on no observed effect concentration and 10% effect concentration toxicity data

The situation for DDT was that:

- it biomagnifies and this needs to be accounted for in deriving the SQG
- there were sufficient toxicity data to use the BurrliOZ software
- the data could not be normalised to the Australian reference soil as there were no normalisation relationships available for DDT
- the toxicity data could not be expressed in terms of added concentrations
- an ABC of 0 was used.

Therefore, a single value was generated by BurrliOZ (Campbell et al. 2000) for each of the three land uses (that is, national park/area with high ecological value, urban residential/public open space, and commercial/industrial). The output was the $SQG_{(NOEC\ \&\ EC10)}$ for that particular land use and no soil-specific SQGs could be calculated. As DDT biomagnifies, the SQGs must take this into account. The methodology for deriving SQGs (Schedule B5b) for biomagnifying contaminants is to increase the level of protection (% of species to be protected) by 5% for soils for urban residential/public open space and commercial/industrial land uses to 85% and 65% of species respectively. For national park/area with high ecological value land uses no increase in the level of protection is recommended (Schedule B5b) as the default level (that is, for non-biomagnifying contaminants) is already 99% protective of species. The methodology was adopted and the resulting $SQG_{(NOEC\ \&\ EC10)}$ values are presented in Table 43.

Table 43. Soil quality guidelines based on no observed effect concentration and 10% effect concentration toxicity data ($SQG_{(NOEC\ \&\ EC10)}$) for DDT in freshly contaminated soils with different land uses.

Land use	$SQG_{(NOEC\ \&\ EC10)}$ (mg total DDT/kg soil)
Nation park/area with high ecological value	1[a]
Urban residential/public open space	70[b]
Commercial/industrial	250[c]

[a] to protect 99% of species, [b] to protect 85% of species, [c] to protect 65% of species.

It should be noted that if a site-specific ABC for DDT is determined (and there is sufficient justification for this ABC to be used instead of the default value of 0 mg/kg) then it may be added to the above generic $SQG_{(NOEC\ \&\ EC10)}$ values to obtain a site-specific $SQG_{(NOEC\ \&\ EC10)}$. As the values in Table 43 are generic $SQG_{(NOEC\ \&\ EC10)}$ values they should be applied to all Australian soils that have the particular land use.

6.6.2 Calculation of soil quality guidelines for fresh DDT contamination based on lowest observed effect concentration data and 30% effect concentration data and based on 50% effect concentration toxicity data

The $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values were calculated using the same method as that for the corresponding values for Zn, As and naphthalene. The data used to calculate these SQGs are presented in Table 42. To maximise the data available to generate the $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values, the available toxicity data were converted to the appropriate measure of toxicity using the default conversion factors recommended in Schedule B5b and presented in Table 30.

As with the $SQG_{(NOEC\ \&\ EC10)}$ values for DDT, soil-specific $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values could not be generated, rather a single generic $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ were generated for each of the three land uses (Table 44). As these are generic SQGs, they should be applied to all Australian soils with the particular land use.

Table 44. Soil quality guidelines for DDT in freshly contaminated soil with different land uses based on lowest observed effect concentration and 30% effect concentration toxicity data and based on 50% effect concentration toxicity data.

Land use	$SQG_{(LOEC\ \&\ EC30)}$ (mg/kg total DDT)	$SQG_{(EC50)}$ (mg/kg total DDT)
National park/area with high ecological value	3	6
Urban residential/public open space	180	360
Commercial/industrial	640	1300

6.7 Calculation of soil quality guidelines for aged contamination

There is currently no ageing or leaching factor available for DDT and therefore SQGs for aged contamination could not be derived.

6.8 Reliability of soil quality guidelines

The DDT SQGs were considered to be of medium reliability as the toxicity data set met the minimum data requirements to use a SSD method but there were no normalisation relationships available to account for soil characteristics (Schedule B5b).

6.9 Important metabolites of DDT

The most common metabolites of DDT are shown in Table 45. DDE is a well-known metabolite of DDT and is relatively well studied. However, there is considerably less information available on the environmental fate, metabolism, degradation and toxicity of these metabolites than on DDT. The HILs and some soil quality guidelines use a sum of DDT, DDE and DDD concentration as a SQG , for example, the Dutch and Flemish SQGs. A SQG could be derived for the sum of DDT, DDE and DDD by assuming the compounds have concentration additive toxicity.

Table 45. Major metabolites of DDT (Sourced from WHO 1989)

Abbreviation of metabolite	Chemical name of metabolite
DDE	1,1'-(2,2-dichloroethenylidene)-bis[4-chlorobenzene]
TDE(DD)	1,1'-(2,2-dichloroethylidene)-bis[4-chlorobenzene]
DDMU	1,1'-(2-chloroethenyldene)-bis[4-chlorobenzene]
DDMS	1,1'-(2-chloroethylidene)-bis[4-chlorobenzene]
DDNU	1,1'-bis(4-chlorophenyl)ethlyene
DDOH	2,2-bis(4-chlorophenyl)ethanol
DDA	2,2-bis(4-chlorophenyl)-acetic acid
Methoxychlor	1,1'-(2,2,2-trichloroethylidene)-bis[4-methoxybenzene]
Perthane	1,1'-(2,2-dichloroethylidene)-bis[4-ethylbenzene]
DFDT	1,1'-(2,2,2-trichloroethylidene)-bis[4-fluorobenzene]

6.10 Comparison with other guidelines

Soil quality guidelines for DDT in a number of jurisdictions are presented in Table 46. These SQGs have a variety of purposes and levels of protection and therefore a comparison of the values is problematic. The SQGs for DDT range from 0.01 to 4 mg/kg total DDT both from the Netherlands. The NEPM (NEPC 1999a) did not include an EIL for DDT. However, there are four HIL values of 260, 700, 400 and 4000 mg/kg for land use settings A, B, C and D[3] for the sum of DDT, DDD, and DDE (Schedule B1). The SQGs for urban residential/public open space soil contaminated with fresh DDT based on NOEC & EC10, LOEC & EC30, and EC50 data were 70, 170 and 350 mg/kg. These values are considerably higher than the SQGs from other jurisdictions and this reflects the different methods that are used to account for biomagnification. The $SQG_{(NOEC\ and\ EC10)}$ and $SQG_{(LOEC\ \&\ EC30)}$ are approximately 27% and 67% respectively, of the HIL for the standard residential setting (that is, setting A) which assumes direct exposure and the consumption of some food grown on the contaminated soil. The SQGs should still offer a considerable degree of protection.

Table 46. Soil quality guidelines for DDT in a number of jurisdictions.

Name of the DDT soil quality guideline	Value of the guideline (mg/kg as total)
Dutch target values[1]	0.01
Dutch intervention value[1]	4
Canadian SQG (residential)[2]	0.7
Eco-SSL plants[3]	NA
Eco-SSL soil invertebrates[3]	NA
Eco-SSL avian[3]	0.093
Eco-SSL mammalian[3]	0.021
EU potentially unacceptable (residential)[4]	1 to 4

1 = VROM 2000
2 = CCME 1999d,, 2006 and http://www.ccme.ca/publications/list_publications.html#link2
3 = http://www.epa.gov/ecotox/ecossl/
4 = Carlon 2007
NA = not available.

[3] A = the standard residential setting with garden/accessible soils and home-grown produce contributing < 10% of vegetable and fruit intake. B = residential with minimal opportunities for soil access: includes dwellings with fully and permanently paved yard space such as high rise apartments and flats. C = parks, recreational open space and playing fields: includes secondary schools. D = Commercial/industrial: includes premises such as shops and offices as well as factories and industrial sites.

7 Copper

7.1 Copper compounds considered

The following compounds were considered in deriving the SQGs for Cu:

- copper metal (CAS No. 7440-50-8)
- copper (II) sulphate pentahydrate (CAS No. 7758-98-7)
- copper (I) oxide (CAS Nos 1317-3-1)
- copper (II) oxide (CAS No. 1317–38–0)
- dicopper chloride trihydroxide (CAS No. 1332-65-6).

7.2 Exposure pathway assessment

The two key considerations in determining the most important exposure pathways for inorganic contaminants are whether they biomagnify and whether they have the potential to leach to groundwater.

A surrogate measure of the potential for a contaminant to leach is its water to soil partition coefficient (Kd). If the logarithm of the Kd (log Kd) of an inorganic contaminant is less than 3, then it is considered to have the potential to leach to groundwater (Schedule B5b). The Australian National Biosolids Research Program measured the log Kd of Cu in 17 agricultural soils throughout Australia. These measurements showed that in most soils the log Kd of Cu was below 3 L/kg (unpublished data). The log Kd value for Cu reported by Crommentuijn et al. (2000) was 2.99 L/kg. Therefore, there is the potential for Cu in some soils to leach to groundwater and affect aquatic ecosystems. However, the methodology for SQG derivation (Schedule B5b) does not advocate the routine derivation of SQGs that account for leaching potential. Rather, it advocates that this be done on a site-specific basis as appropriate (Schedule B5b).

Copper is an essential element for the vast majority of living organisms and, as such, concentrations of Cu in tissue are highly regulated and it does not biomagnify (Louma & Rainbow 2008; Heemsbergen et al. 2008; EC 2008a). Therefore, the biomagnification route of exposure does not need to be considered for Cu and the SQGs will only account for direct toxicity.

7.3 Toxicity data

The ecotoxicology of Cu has been extensively studied both within Australia and internationally. Most studies presented their toxicity data as an added concentration (that is, the concentration of the contaminant added to the soil that causes a specified toxic effect) or in a form which permitted the added concentration to be calculated (that is, by subtracting the background from the total concentration).

The toxicity database used to calculate the SQGs for Cu consisted of over 400 toxicity data for 11 soil processes (Table 47), 10 invertebrate species (Table 48) and 18 plant species (Table 49). The raw data used to generate Tables 47–49 are provided in Appendix E. There were sufficient data — that is, toxicity data for at least five species or soil processes that belong to at least three taxonomic or nutrient groups (Schedule B5b) — available to derive SQGs using a species sensitivity distribution (SSD) methodology.

Given that Cu does not biomagnify, the level of protection recommended in the SQG derivation methodology for urban residential/public open space land is 80% (that is, 80% of species would be protected) (Schedule B5b).

Table 47. The lowest geometric mean values of the normalised copper (Cu) toxicity data (expressed in terms of added Cu) for soil microbial processes.

Soil process	Geometric means (mg/kg added Cu)		
	EC10 or NOEC	EC30 or LOEC	EC50
Ammonification	721	1081	2164
Denitrification	59.6	149	179
Glutamic acid decomposition	64.7	329	659
Maize residue mineralisation	199	299	597
Microbial biomass carbon	35.6	80.9	107
Microbial biomass nitrogen	141	90.9	174
N mineralisation	81	84	160
Potential nitrification rate	137	205	282
Repiration	151	916	3165
Substrate induced nitrification	276	421	700
Substrate induced respiration	86	224	589

Table 48. The lowest geometric mean values of the normalised copper (Cu) toxicity data (expressed in terms of added Cu) for soil invertebrate species.

Species		Geometric means (mg/kg added Cu)		
Common name	Scientific name	EC10 or NOEC	EC30 or LOEC	EC50
Earthworm	*Eisenia andrei*	44.3	66.5	133
Earthworm	*Eisenia fetida*	61.4	129	169
Earthworm	*Lumbriculus rubellus*	42.4	117	656
Mite	*Hypoapsis aculeifer*	195	293	586
Mite	*Platynothrus peltifer*	70.7	106	212
Nematode	*Plectus acuminatus*	27.6	86.4	259
Potworm	*Cognettia sphagnetorum*	36.2	61.7	94.6
Springtail	*Folsomia fimetaria*	265	398	630
Springtail	*Folsomia candida*	205	343	499
Springtail	*Isotoma viridis*	135	202	405

Table 49. The lowest geometric mean values of the normalised copper (Cu) toxicity data (expressed in terms of added Cu) for individual plant species.

Plant species		Geometric means (mg/kg added Cu)		
Common name	**Scientific name**	**EC10 or NOEC**	**EC30 or LOEC**	**EC50**
Annual meadow grass	*Poa annua*	99.4	90.2	140
Barley	*Hordeum vulgare*	47.5	74.6	187
Canola	*Brassica napus*	825	1157	1125
Cotton	*Gossypium sp.*			
Groundsel	*Senico vulgaris*	27.8	56.4	87.7
Maize	*Zea mays*			
Millet	*Panicum milaceum*			
Oats	*Avena sativa*	147	221	442
Peanuts	*Arachis hypogaea*			
Perennial ryegrass	*Lolium perenne*	69.5	374	690
Smooth hawkesbeard	*Hypochoeris radicata*	98.2	164	186
Sorghum	*Sorghum sp.*			
Sugar cane	*Sacharum sp.*			
Tomato	*Lycopersicon esculentum*	126	196	325
Triticale	*Tritosecale sp.*			
Wheat	*Triticum aestivum*			
Wild buckwheat	*Polygonum convolvulus*	124	196	169
Daisy family	*Andryala integrifolia*	75.5	105	127

7.4 Normalisation relationships

A normalisation relationship is an empirical model that predicts the toxicity of a single contaminant to a single species using soil physicochemical properties (for example, soil pH and organic carbon content). Normalisation relationships are used to account for the effect of soil characteristics on toxicity data. Thus, when toxicity data are normalised the effect of soil properties on the toxicity should be removed, so the resulting toxicity data should more closely reflect the inherent sensitivity of the test species.

Eighteen normalisation relationships were reported in the literature for Cu toxicity and an additional two were derived as part of this study (Table 50), giving a total of 20 normalisation relationships. Six were developed for Australian soils (Broos et al. 2007; Warne et al. 2008a; Warne et al. 2008b) and fourteen have been derived for European soils (Oorts et al. 2006b; Rooney et al. 2006; Criel et al. 2008; EC 2008a). Eight of the relationships were for plants, six for soil invertebrates, and six for microbial functions (Table 50).

The choice of normalisation relationships to be used to normalise the toxicity data was based on (1) regional relevance, (2) whether they are based on field- or laboratory-based toxicity data; preference is given to field-based relationships as they provide better estimates of toxicity in the field (Warne et al. 2008b), (3) providing 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 (that is, r^2), and (5) the number of species to which the relationships apply.

Thus, whenever there were appropriate Australian normalisation relationships, these were applied to Australian toxicity data and the same rule applied to European normalisation relationships.

Of the Australian relationships, number 1 was not used as an equivalent field-based relationship for Australian soils was available (relationship 3) and relationship 2 was not used as ultimately it is the amount of harvestable food that is most important when considering crops. The best relationship developed by Broos et al. (2007) for substrate induced nitrification, (SIN) (relationship 4) was based on EC50 and pH. However, to be consistent with all the other normalisation relationships developed, the data were re-analysed using the logarithm of the EC50 data, which resulted in relationship 5 used in this Schedule. Relationship 7 was not used as relationships not explaining at least 60% of the variation are not considered appropriate for normalisation (Warne et al. 2008b). Relationship 3 was used to normalise all the Australian plant toxicity data and relationship 5 was used to normalise all the Australian microbial process toxicity data.

Of the European relationships, number 8 rather than 7 was used for barley as it contained fewer parameters and had a marginally higher r^2 value. Relationship 11 was used for tomato rather than relationships 9 and 10, as Fe oxide content of soils was not reported in the vast majority of the toxicity data and as relationship 11 had a lower gradient than relationship 10. For *E. fetida* relationship 13 was used as it had a lower gradient than relationship 12. Similarly, relationship 16 for *F. candida* was used rather than relationships 14 or 15 as it had a lower gradient.

All the toxicity data for European plant species, apart from barley, were normalised using relationship 11 for tomato as it was the plant relationship with the lowest gradient. All the European invertebrate toxicity data were normalised using relationship 13 for *E. fetida* as it was the invertebrate relationship with the lowest gradient and relationship 18 for SIR was used to normalise all European microbial process toxicity data (except that for maize residue mineralisation and potential nitrification rate) as it was the microbial process relationship with the lowest positive gradient.

All the Cu toxicity data in Tables 47–49 were normalised to their equivalent toxicity in the recommended Australian reference soil (Schedule B5b) (Table 6). Depending on the conditions under which the toxicity tests were conducted, the normalised toxicity data could be higher or lower in the reference soil compared to the original toxicity data in the test soil.

Table 50. Normalisation relationships for the toxicity of copper (Cu) to plants, soil invertebrates and soil processes. The relationships used to normalise the toxicity data are in bold.

Eqtn no.	Species/soil process	Y parameter	X parameter(s)	Reference
Australian relationships				
1	*Triticum aestivum* (wheat)	log EC10[a] (laboratory-based data)	0.98 log CEC[b] – 2.97 EC + 2.01 (r^2 adj = 0.79)	Warne et al. 2008a
2	*T. aestivum* (wheat)	log EC50 (field-based 8wk growth)	0.54 pH[c] – 0.16 (r^2 adj = 0.85)	Warne et al. 2008b
3	*T. aestivum* (wheat)	log EC10 (field-based grain yield)	**0.31 pH[c] + 1.05 log OC + 0.56** (r^2 adj = 0.80)	Warne et al. 2008b
4	SIN	EC50	434 pH[c] – 1615 (r^2 adj = 0.73)	Broos et al. 2007
5	SIN	log EC50	**0.35 pH[c] + 0.84** (r^2 adj = 0.72)	This study
6	SIR	EC50[d]	22 clay + 641 (r^2 adj = 0.38)	Broos et al. 2007

cont'd over

Northern hemisphere relationships				
7	*Hordeum vulgare* (barley)	log EC10[a]	0.403 log CEC[e] + 0.42 OC + 0.809 (r^2 adj = 0.63)	Rooney et al. 2006
8	*H. vulgare* (barley)	log EC50	**1.06 log CEC[e] + 1.42** (r^2 = 0.66)	EC 2008a
9	*Lycopersicon esculentum* (tomato)	log EC10[a]	0.855 log CEC[e] + 0.388 log Fe oxide – 0.047 (r^2 adj = 0.72)	Rooney et al. 2006
10	*L. esculentum* (tomato)	log EC10[a]	0.99 log CEC[e, f]	EC 2008a
11	*L. esculentum* (tomato)	log EC50	**0.96 log CEC[e] + 1.47** (r^2 = 0.75)	EC 2008a
12	*Eisenia fetida* (earthworm)	log EC10	0.606 log CEC[e] + 1.56 (r^2 = 0.65)	Criel et al. 2008
13	*E. fetida* (earthworm)	log EC50	**0.58 log CEC[e] + 1.85** (r^2 = 0.75)	EC 2008a
14	*Folsomia candida* (collembola)	log EC10	1.16 log CEC[e] + 1.1 (r^2 = 0.54)	Criel et al. 2008
15	*F. candida* (collembola)	log EC50	0.96 log CEC[e] + 1.63 (r^2 = 0.63)	EC 2008a
16	*F. candida* (springtail)	Log EC10	**0.8475 log CEC[e] + 1.499** (r^2 = 0.56)	This study
17	*F. fimetria* (springtail)	Log EC10	0.7508 log CEC[e] + 2.0868 (r^2 = 0.63)	This study
18	SIR	log EC50	0.66 log OC + 1.96 (r^2 = 0.57)	Oorts et al. 2006b
19	MRM	log EC20	-0.26 pH[c] + 4.05 (r^2 = 0.52)	Oorts et al. 2006b
20	PNR	log EC50	1.06 log CEC[e] + 1.41 (r^2 = 0.66)	Oorts et al. 2006b

a = normalisation relationships were also developed for the same combination of species and endpoint but for different measures of toxicity e.g. log EC50 and NOEC and using other soil physicochemical properties.
b = these CEC measurements were made using the ammonium acetate method (Rayment & Higgins 1992).
c = pH measured in 0.01 M calcium chloride (Rayment & Higgins 1992).
d = no statistically significant normalisation relationships could be derived for EC10 and EC10 SIR data (NBRP unpublished data).
e = these CEC measurements were made using the silver thiourea method (Chhabra et al. 1975).
f = the full normalisation relationship was not provided in EC (2008a) but as only the slope of the relationship is used in the normalising the constant is not necessary. CEC = cation exchange capacity ($cmol_c$/kg); OC = organic carbon content (%); MRM = maize residue mineralisation; PNR = potential nitrification rate; SIN = substrate induced nitrification, SIR = substrate induced respiration.

7.5 Sensitivity of organisms to copper

The distribution of the sensitivity of species and microbial processes to Cu is presented in Figure 7. Toxicity data for plants, soil processes and soil invertebrates were generally evenly spread in the species sensitivity distribution (SSD); however, the invertebrates did not have the same range of highly tolerant species as the other two organism groups. Nonetheless, the overall distribution of sensitivity to Cu was similar. Therefore, all the toxicity data were used to derive the ACLs and SQGs.

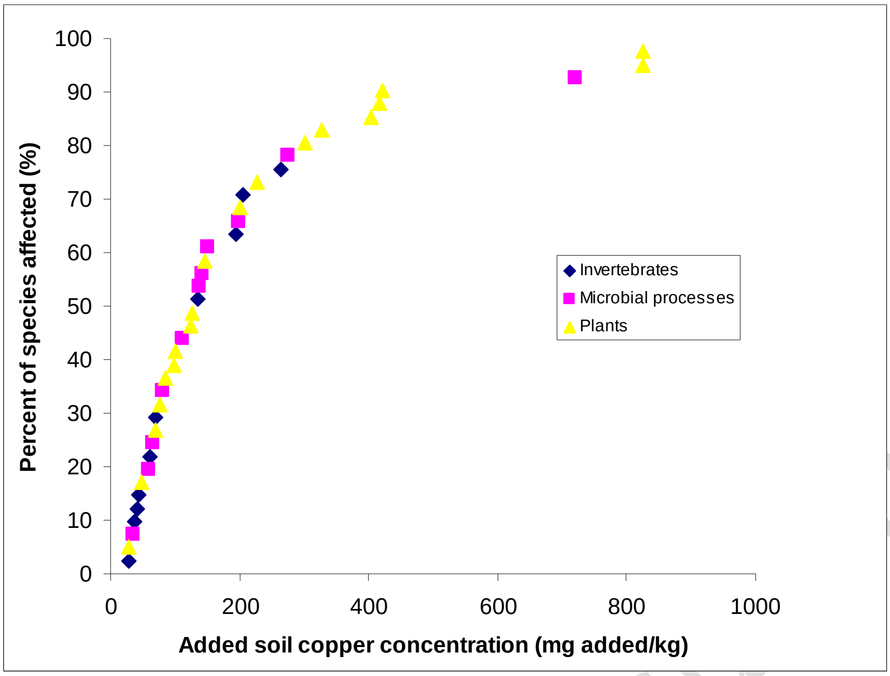


Figure 7. The species sensitivity distribution (plotted as a cumulative frequency against added copper (Cu) concentration) for soil processes, soil invertebrates and plant species to Cu.

7.6 Calculation of soil quality guidelines for fresh copper contamination

As described earlier, SQGs were derived using three sets of toxicity data – NOEC and EC10, LOEC and EC30, and EC50 data.

7.6.1 Calculation of soil quality guidelines for fresh copper contamination based on no observed effect concentration and 10% effect concentration toxicity data

7.6.1.1 Calculation of soil-specific added contaminant limits

The NOEC and EC10 toxicity data were normalised as outlined in Heemsbergen et al. (2008). Geometric means for each toxic end-point (for example, mortality, reproduction, seedling emergence) for each species were calculated and the lowest geometric mean selected to represent the sensitivity of each species/microbial process. These lowest geometric means were entered into the BurrliOZ software (Campbell et al. 2000) and $ACL_{(NOEC \& EC10)}$ values calculated that should theoretically protect 99, 80 and 60% of species/microbial processes. The resulting $ACL_{(NOEC\ and\ EC10)}$ values are only applicable to the Australian reference soil (Table 6). In order to generate soil-specific ACLs the normalisation relationships were applied to the $ACL_{(NOEC \& EC10)}$ values in the reverse manner.

A complicating factor for Cu is that there are different soil physicochemical properties (that is, CEC, pH, OC and a combination of pH and log OC) that control the toxicity of Cu depending on the species or microbial process (Table 50). However, these can be rationalised down to two factors that control the ACL, namely CEC (measured using the silver thiourea method, Chhabra et al. 1975) and pH (measured in 0.01M $CaCl_2$, Rayment & Higginson 1992) (see Appendix F for a detailed explanation of this rationalisation). Thus, there are two sets of ACL values for each land-use type (that is, a set that vary with CEC and a second set that vary with pH). To determine the ACL that applies to a site, it is simply a matter of measuring the CEC and pH of the soil, looking up the tables for the appropriate ACL and then adopting the lower of the two ACL values. However, in the majority of cases the pH-based ACL values will limit how much Cu can be added to a soil when the soil pH is less than or equal to 6, while the CEC-based ACL values will limit the amount of Cu that can be added to a soil when the soil pH is greater than 6.

The ACL values for national park/area withhigh ecological value, urban residential/public open space and commercial/industrial land uses are presented in Tables 51 to 53, respectively.

Table 51. Soil-specific added contaminant limits (ACLs, mg/kg) based on no observed effect concentration (NOEC) and 10% effect concentration (EC10) toxicity data for fresh copper (Cu) contamination that theoretically protect at least 99% of soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.5 to 8 and a cation exchange capacity (CEC) ranging from 5 to 60 $cmol_c$/kg and a national park/area with high ecological value land use. The lowest of the CEC- or the pH-derived ACLs that apply to a soil is the $ACL_{(NOEC \& EC10)}$ to be used.

Type of ACL	CEC ($cmol_c$/kg)[a]					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	10	20	25	25	25	25
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	7	15	20	30	65	90

a = CEC was measured using the silver thiourea method (Chhabra et al. 1972).
b = pH was measured using the $CaCl_2$ method (Rayment & Higginson1992).

Table 52. Soil-specific added contaminant limits (ACLs, mg/kg) based on no observed effect concentration (NOEC) and 10% effect concentration (EC10) toxicity data for fresh copper (Cu) contamination that theoretically protect at least 80% of soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.5 to 8 and a cation exchange capacity (CEC) ranging from 5 to 60 $cmol_c$/kg and a urban residential/public open space land use. The lowest of the CEC- or the pH-derived ACLs that apply to a soil is the $ACL_{(NOEC \& EC10)}$ to be used.

Type of ACL	CEC ($cmol_c$/kg)[a]					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	30	60	65	65	70	70
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	20	40	60	85	170	250

a = CEC was measured using the silver thiourea method (Chhabra et al. 1972).
b = pH was measured using the $CaCl_2$ method (Rayment & Higginson 1992).

Table 53. Soil-specific added contaminant limits (ACLs, mg/kg) based on no observed effect concentration (NOEC) and 10% effect concentration (EC10) toxicity data for fresh copper (Cu) contamination that theoretically protect at least 60% of soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.5 to 8 and a cation exchange capacity (CEC) ranging from 5 to 60 $cmol_c$/kg and a commercial/industrial land use. The lowest of the CEC- or the pH-derived ACLs that apply to a soil is the $ACL_{(NOEC \& EC10)}$ to be used.

Type of ACL	CEC ($cmol_c$/kg)[a]					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	45	90	100	100	110	110
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	30	60	90	130	270	380

a = CEC was measured using the silver thiourea method (Chhabra et al., 1972). b = pH was measured using the $CaCl_2$ method (Rayment and Higginson, 1992).

7.6.1.2 Calculation of ambient background concentration values

To convert $ACL_{(NOEC \& EC10)}$ values to $SQG_{(NOEC \& EC10)}$ values, the ambient background concentration (ABC) needs to be added to the $ACL_{(NOEC \& EC10)}$. Three methods of determining the ABC were recommended in the methodology for deriving SQGs (Heemsbergen et al. 2008).

The preferred method is to measure the ABC at an appropriate reference site. However, where this is not possible the methods of Olszowy et al. (1995) and Hamon et al. (2004) were recommended to predict the ABC where there has been and has not been, respectively, a history of contamination. In the Hamon et al. (2004) method, the ABC for a variety of metal contaminants, including Cu, vary with either the soil iron or manganese content. The equation to predict the ABC for Cu in soils with no history of Cu contamination (Hamon et al. 2004) is:

$$\log \text{Cu conc (mg/kg)} = 0.612 \log \text{Fe content (\%)} + 0.808 \qquad \textit{(equation 7)}$$

Examples of the ABC values predicted by this equation are presented in Table 54.

Table 54. Ambient background concentrations (ABCs) for copper (Cu) predicted using the Hamon et al. (2004) method (equation 7 above).

Fe content (%)	Predicted Cu ABC (mg/kg)
0.1	2
0.5	4
1	6
2	10
5	15
10	25
15	35
20	40

Predicted ABC values for Cu range from approximately 2 to 40 mg/kg in soils with iron contents between 0.1 and 20%.

7.6.1.3 Examples of soil quality guidelines for fresh copper contamination based on no observed effect concentration and 10% effect concentration data

To calculate an $SQG_{(NOEC\ \&\ EC10)}$, the ABC value is added to the $ACL_{(NOEC\ \&\ EC10)}$. Ambient background concentration values vary with soil type. Therefore it is not possible to present a single set of SQGs. Thus, two examples of $SQG_{(NOEC\ \&\ EC10)}$ values for urban settings are presented below. These examples would be at the low and high end of the range of $SQG_{(NOEC\ \&\ EC10)}$ values (but not the extreme values) generated for Cu in Australian soils.

Example 1

Site descriptors - urban residential/public open space land use in a new suburb (that is, fresh Cu contamination).

Soil descriptors – a sandy acidic soil (pH 5.5, CEC 10) with 1% iron content.

The resulting $ACL_{(NOEC\ \&\ EC10)}$, ABC and $SQG_{(NOEC\ \&\ EC10)}$ values are:

$ACL_{(NOEC\ \&\ EC10)}$ CEC-based:	60 mg/kg
$ACL_{(NOEC\ \&\ EC10)}$ pH-based:	40 mg/kg
$ACL_{(NOEC\ \&\ EC10)}$:	40 mg/kg (the lower of the two ACLs that apply to this soil)
ABC:	6 mg/kg
$SQG_{(NOEC\ \&\ EC10)}$:	46 mg/kg (which would be rounded off to 45 mg/kg)

Example 2

Site descriptors - commercial/industrial land use in a new suburb (that is, fresh Cu contamination).

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(NOEC\ \&\ EC10)}$, ABC and $SQG_{(NOEC\ \&\ EC10)}$ values are:

$ACL_{(NOEC\ \&\ EC10)}$ CEC-based:	100 mg/kg
$ACL_{(NOEC\ \&\ EC10)}$ pH-based:	270 mg/kg
$ACL_{(NOEC\ \&\ EC10)}$:	100 mg/kg (the lower of the two ACLs that apply to this soil)
ABC:	25 mg/kg
$SQG_{(NOEC\ \&\ EC10)}$:	125 mg/kg

7.6.2 Calculation of soil quality guidelines for fresh copper contamination based on lowest observed effect concentration and 30% effect concentration toxicity data and on 50% effect concentration data

7.6.2.1 Calculation of soil-specific added contaminant limits

In addition to calculating $SQG_{(NOEC\ \&\ EC10)}$ values, Heemsbergen et al. (2008) suggested that two other sets of SQGs could be generated using either a combination of LOEC and EC30 data or EC50 data. These SQGs are termed the $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ respectively. These additional SQGs were calculated using the method described in Heemsbergen et al. (2008) except the input data for the SSD were changed to the appropriate type (Table 1). The lowest geometric means of the normalised toxicity data used to generate these SQGs are presented in Tables 47 to 49 and the raw data can be found in Appendix E. Lowest observed effect concentration, 30% effect concentration and 50% effect concentration toxicity data were not available in all instances; therefore, to maximise the data available to calculate $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values the available NOEC and EC10 toxicity data were converted to these measures using conversion factors if necessary. The NBRP developed experimentally derived conversion factors (cited in Heemsbergen et al. 2008) for Cu and Zn (Table 17). These conversion factors were used rather than the generic conversion factors often used to convert toxicity data. This approach is consistent with the recommendation of Heemsbergen et al. (2008). Tables 55 and 56 show the soil-specific $ACL_{(LOEC\ \&\ EC30)}$ and $ACL_{(EC50)}$ values respectively, for soils with national park/area with high ecological value, urban residential/public open space and commercial/industrial land uses.

Table 55. Soil-specific ACLs (mg/kg) based on lowest observed effect concentration (LOEC) and 30% effect concentration (EC30) data for fresh copper (Cu) contamination that should theoretically provide the appropriate level of protection (that is, 99, 80 or 60% of species) to soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.5 to 8 and a CEC ranging from 5 to 60 $cmol_c$/kg for various land uses. The lowest of the CEC- or the pH-derived ACLs for a particular land use that apply to a soil is the $ACL_{(LOEC \& EC30)}$ to be used.

National park/area with high ecological value land use						
Type of ACL	**CEC ($cmol_c$/kg)[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	25	50	50	55	55	60
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	15	30	50	70	140	200
Urban residential/public open space land use						
Type of ACL	**CEC($cmol_c$/kg)[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	50	100	110	110	120	120
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	30	70	100	140	290	420
Commercial/industrial land use						
Type of ACL	**CEC ($cmol_c$/kg)[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	70	150	160	170	170	180
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	45	100	150	210	440	630

a = CEC was measured using the silver thiourea method (Chhabra et al. 1972).
b = pH was measured using the $CaCl_2$ method (Rayment & Higginson 1992).

Table 56. Soil-specific ACLs (mg/kg) based on 50% effect concentration (EC50) data for fresh copper (Cu) contamination that should theoretically provide the appropriate level of protection (that is, 99, 80 or 60% of species) to soil processes processes, soil invertebrate species and plant species in soils with a pH ranging from 4.5 to 8 and a cation exchange capacity (CEC) ranging from 5 to 60 $cmol_c$/kg for various land uses. The lowest of the CEC- or the pH-derived ACLs for a particular land use that apply to a soil is the $ACL_{(EC50)}$ to be used.

National park/area with high ecological value use						
Type of ACL	**CEC ($cmol_c$/kg)[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	35	75	85	85	90	95
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	25	50	75	110	230	320
Urban residential/public open space land use						
Type of ACL	**CEC[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	85	170	190	200	200	210
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	50	120	170	250	510	730

cont'd over

Commercial/industrial land use						
Type of ACL	**CEC (cmol$_c$/kg)[a]**					
CEC-based ACLs	**5**	**10**	**20**	**30**	**40**	**60**
	125	260	280	290	310	320
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	80	180	260	380	770	1100

a = CEC was measured using the silver thiourea method (Chhabra et al. 1972).
b = pH was measured using the $CaCl_2$ method (Rayment & Higginson 1992).

7.6.2.2 Calculation of ambient background concentration values

The ABC values were calculated using the method described earlier and the values presented in Table 54.

7.6.2.3 Examples of soil quality guidelines for fresh copper contamination in Australian soils based on lowest observed effect concentration and 30% effect concentration toxicity data and on 50% effect concentration data.

As the ACL and ABC values are both soil specific it is not possible to generate a single set of SQGs. Example SQGs that represent values that at the upper and lower end of the range of values that would be encountered in urban situations are presented. Two examples are presented for SQGs based on LOEC and EC30 data and two examples based on EC50 data.

SQG$_{(LOEC\ \&\ EC30)}$ - Example 1

Site descriptors - urban residential/public open space land use in a new suburb.

Soil descriptors – a sandy acidic soil (pH 5.5, CEC 10) with 1% iron content.

The resulting ACL$_{(LOEC\ \&\ EC30)}$, ABC and SQG$_{(LOEC\ \&\ EC30)}$ values are:

ACL$_{(LOEC\ \&\ EC30)}$ CEC-based: 100 mg/kg

ACL$_{(LOEC\ \&\ EC30)}$ pH-based: 70 mg/kg

ACL$_{(NOEC\ \&\ EC10)}$: 70 mg/kg (the lower of the two ACLs that apply to this soil)

ABC: 6 mg/kg

SQG$_{(LOEC\ \&\ EC30)}$: 76 mg/kg which would be rounded off to 75 mg/kg

SQG$_{(LOEC\ \&\ EC30)}$ - Example 2

Site descriptors - commercial/industrial land use in a new suburb.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting ACL$_{(LOEC\ \&\ EC30)}$, ABC and SQG$_{(LOEC\ \&\ EC30)}$ values are:

ACL$_{(LOEC\ \&\ EC30)}$ CEC-based: 170 mg/kg

ACL$_{(LOEC\ \&\ EC30)}$ pH-based: 440 mg/kg

ACL$_{(NOEC\ \&\ EC10)}$: 170 mg/kg (the lower of the two ACLs that apply to this soil)

ABC: 25 mg/kg

SQG$_{(LOEC\ \&\ EC30)}$: 195 mg/kg which would be rounded off to 190 mg/kg

$SQG_{(EC50)}$ - Example 1

Site descriptors - urban residential/public open space land use in a new suburb.

Soil descriptors – a sandy acidic soil (pH 5.5, CEC 10) with 1% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$ CEC-based:	170 mg/kg
$ACL_{(EC50)}$ pH-based:	120 mg/kg
$ACL_{(EC50)}$:	120 mg/kg (the lower of the two ACLs that apply to this soil)
ABC:	6 mg/kg
$SQG_{(EC50)}$:	126 mg/kg which would be rounded off to 125 mg/kg

$SQG_{(EC50)}$ - Example 2

Site descriptors - commercial/industrial land use in a new suburb.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$ CEC-based:	310 mg/kg
$ACL_{(EC50)}$ pH-based:	770 mg/kg
$ACL_{(EC50)}$:	310 mg/kg (the lower of the two ACLs that apply to this soil)
ABC:	25 mg/kg
$SQG_{(EC50)}$:	335 mg/kg which would be rounded off to 330 mg/kg

7.7 Calculation of soil quality guidelines for aged copper contamination

7.7.1 Calculation of an ageing and leaching factor for copper

In addition to calculating SQGs in recently contaminated soils (that is, contamination is < 2 years old) Heemsbergen et al. (2008) suggested that an identical set of SQGs could be derived for soils where the contamination is aged (that is, it has been present for ≥ 2 years). The Cu $SQG_{(NOEC \& EC10)}$, $SQG_{(LOEC \& EC30)}$ and $SQG_{(EC50)}$ values for aged sites were calculated using the methods set out in earlier sections, the only difference being that laboratory toxicity data based on freshly spiked soils or soils that had not been leached were multiplied by an ALF (Schedule B5b). An ALF of 2 was developed by Smolders et al. (2009) while a value of 2.2 was developed and used in the EC ecological risk assessment for Cu (EC 2008a). Given the uniformity of these ALF values and to err on the conservative side (that is to offer greater protection to the environment), an ALF of 2 was adopted in this study.

7.7.2 Calculation of soil quality guidelines for aged copper contamination based on no observed effect concentration and 10% effect concentration toxicity data

7.7.2.1 Calculation of soil-specific added contaminant limits

The raw toxicity data (Appendix E) for Cu that were generated using freshly spiked and non-leached soils were multiplied by the ALF of 2. Those data that were field-based and aged and/or leached laboratory-based data were not multiplied by the ALF. In all other ways the aged $ACL_{(NOEC \& EC10)}$ and $SQG_{(NOEC \& EC10)}$ values were calculated using the same methods as described in earlier sections. The resulting soil-specific $ACL_{(NOEC \& EC10)}$ values for aged Cu contamination are presented in Table 57.

Table 57. Soil-specific ACLs (mg/kg) based on no observed effect concentration (NOEC) and 10% effect concentration (EC10) data for aged copper (Cu) contamination that should theoretically provide the appropriate level of protection (i.e., 99, 80 or 60% of species) to soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.5 to 8 and a CEC ranging from 5 to 60 $cmol_c$/kg for various land uses. The lowest of the CEC- or the pH-derived ACLs for a particular land use that apply to a soil is the aged $ACL_{(NOEC\ \&\ EC10)}$ to be used.

National park/area with high ecological value land use						
Type of ACL	**CEC ($cmol_c$/kg)[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	15	25	30	30	30	35
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	8	20	25	40	80	110
Urban residential/public open space land use						
Type of ACL	**CEC[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	50	110	110	120	120	130
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	30	70	110	150	310	440
Commercial/industrial land use						
Type of ACL	**CEC ($cmol_c$/kg)[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	80	160	180	180	190	200
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	50	110	160	230	480	680

a = CEC was measured using the silver thiourea method (Chhabra et al. 1972).
b = pH was measured using the $CaCl_2$ method (Rayment & Higginson 1992).

7.7.2.2 Calculation of ambient background concentration values

For aged contaminated sites (that is, the contamination has been in-place for at least 2 years) the methodology (Schedule B5b) recommends using the 25th percentiles of the ABC data for the 'old suburbs' from Olszowy et al. (1995) (see Table 58).

Table 58. Copper (Cu) ambient background concentrations (ABC) based on the 25th percentiles of Cu concentrations in 'old suburbs' (that is, > 2 years old) from various states of Australia (Olszowy et al. 1995).

Suburb type	**25th percentile of Cu ABC values (mg/kg)**			
	NSW	**QLD**	**SA**	**VIC**
Old suburb low traffic	20	10	15	10
Old suburb high traffic	30	15	25	10

7.7.2.3 Examples of soil quality guidelines for aged copper contamination in Australian soils based on no observed effect concentration and 10% effect concentration data.

SQGs are the sum of the ABC and ACL values, both of which are soil-specific. It is, therefore, not possible to present a single set of SQGs. Thus, some examples of $SQG_{(NOEC\ \&\ EC10)}$ values for aged urban soils are provided below. These examples represent $SQG_{(NOEC\ \&\ EC10)}$ values that would be at the low and high end of the range of $SQG_{(NOEC\ \&\ EC10)}$ values that would be generated for Cu in Australian soils, but are not extreme values.

Example 1

Site descriptors – urban residential land /public open space use in an old Victorian suburb with low traffic volume.

Soil descriptors – a sandy acidic soil (pH 5.5, CEC 10) with 1% iron and aged Cu contamination and a low traffic volume.

The resulting aged $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:

aged $ACL_{(NOEC \& EC10)}$ CEC-based:	110 mg/kg
aged $ACL_{(NOEC \& EC10)}$ pH-based:	70 mg/kg
aged $ACL_{(NOEC \& EC10)}$:	70 mg/kg (the lower of the two ACLs that apply to this soil)
aged ABC:	10 mg/kg
aged $SQG_{(NOEC \& EC10)}$:	80 mg/kg

Example 2

Site descriptors – commercial/industrial land use in an old South Australian suburb with a high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron and aged Cu contamination.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:

aged $ACL_{(NOEC \& EC10)}$ CEC-based:	190 mg/kg
aged $ACL_{(NOEC \& EC10)}$ pH-based:	480 mg/kg
aged $ACL_{(NOEC \& EC10)}$:	25 mg/kg (the lower of the two ACLs that apply to this soil)
aged ABC:	25 mg/kg
aged $SQG_{(NOEC \& EC10)}$:	215 mg/kg which would be rounded off to 210 mg/kg

7.7.3 Calculation of soil quality guidelines for aged copper contamination based on LOEC and 30% effect concentration toxicity data and on 50% effect concentration data.

7.7.3.1 Calculation of soil-specific added contaminant limits

The $ACL_{(LOEC \& EC30)}$ and $ACL_{(EC50)}$ values for aged Cu contamination were calculated in the same manner as the aged $ACL_{(NOEC \& EC10)}$ values, except that LOEC and EC30 or EC50 toxicity data were used respectively. The aged $ACL_{(LOEC \& EC30)}$ and aged $ACL_{(EC50)}$ values are presented in Tables 59 and 60 respectively.

Table 59. Soil-specific added contaminant limits (ACLs, mg/kg) based on LOEC and 30% effect concentration (EC30) data for aged copper (Cu) contamination that should theoretically provide the appropriate level of protection (i.e. 99, 80 or 60% of species) to soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.5 to 8 and a CEC ranging from 5 to 60 cmol$_c$/kg for various land uses. The lowest of the CEC- or the pH-derived ACLs for a particular land use that apply to a soil is the aged ACL$_{(LOEC\ \&\ EC30)}$ to be used.

National park/area with high ecological value land use						
Type of ACL	**CEC (cmol$_c$/kg)[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	30	65	70	70	75	80
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	20	45	65	90	190	270
Residential urban /public open space land use						
Type of ACL	**CEC (cmol$_c$/kg)[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	95	190	210	220	220	230
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	60	130	190	280	560	800
Commercial/industrial land use						
Type of ACL	**CEC (cmol$_c$/kg)[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	140	280	300	320	330	340
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH-based ACLs	85	190	280	400	830	1200

a = CEC was measured using the silver thiourea method (Chhabra et al. 1972).
b = pH was measured using the $CaCl_2$ method (Rayment & Higginson 1992).

Table 60. Soil-specific ACLs (mg/kg) based on 50% effect concentration (EC50) data for aged copper (Cu) contamination that should theoretically provide the appropriate level of protection (i.e. 99, 80 or 60% of species) to soil processes, soil invertebrate species and plant species in soils with a pH ranging from 4.5 to 8 and a CEC ranging from 5 to 60 cmol$_c$/kg for various land uses. The lowest of the CEC- or the pH-derived ACLs for a particular land use that apply to a soil is the aged ACL$_{(EC50)}$ to be used.

National park/area with high ecological value land use						
Type of ACL	**CEC (cmol$_c$/kg)[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	80	170	180	190	190	200
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH -based ACLs	50	110	170	240	490	700
Urban residential /public open space land use						
Type of ACL	**CEC (cmol$_c$/kg)[a]**					
	5	**10**	**20**	**30**	**40**	**60**
CEC-based ACLs	150	300	350	350	350	400
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH -based ACLs	95	200	300	450	900	1300

cont'd over

Commercial/industrial land use						
Type of ACL	**CEC ($cmol_c$/kg)[a]**					
CEC-based ACLs	**5**	**10**	**20**	**30**	**40**	**60**
	210	440	470	490	510	530
	pH[b]					
	4.5	**5.5**	**6**	**6.5**	**7.5**	**8.0**
pH -based ACLs	130	290	440	630	1300	1800

a = CEC was measured using the silver thiourea method (Chhabra et al., 1972).
b = pH was measured using the $CaCl_2$ method (Rayment and Higginson, 1992).

7.7.3.2 Calculation of ambient background concentration values

The ABC values for aged Cu contamination were calculated using the data from Olszowy et al. (1995) which are presented in Table 58.

7.7.3.3 Examples of soil quality guidelines for aged copper contamination in Australian soils based on no observed effect concentration and 10% effect concentration data

Four examples of SQGs that would apply to aged Cu contamination that represent the range (but not the extremes) of SQGs that would apply to urban residential/public open space and commercial/industrial land uses are presented below.

$SQG_{(LOEC\ \&\ EC30)}$ - Example 1

Site descriptors - urban residential land/public open space use in an old Victorian suburb with a low traffic volume.

Soil descriptors – a sandy acidic soil (pH 5.5, CEC 10) with 1% iron content.

The resulting aged $ACL_{(LOEC\ \&\ EC30)}$, ABC and $SQG_{(LOEC\ \&\ EC30)}$ values are:

aged $ACL_{(LOEC\ \&\ EC30)}$ CEC-based:	190 mg/kg
aged $ACL_{(LOEC\ \&\ EC30)}$ pH-based:	130 mg/kg
aged $ACL_{(LOEC\ \&\ EC30)}$:	130 mg/kg (the lower of the two ACLs that apply to this soil)
aged ABC:	10 mg/kg
aged $SQG_{(LOEC\ \&\ EC30)}$:	140 mg/kg

$SQG_{(LOEC\ \&\ EC30)}$ - Example 2

Site descriptors - commercial/industrial land use in an old South Australian suburb with a high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(LOEC\ \&\ EC30)}$, ABC and $SQG_{(LOEC\ \&\ EC30)}$ values are:

aged ACL(LOEC & EC30) CEC-based:	330 mg/kg
aged ACL(LOEC & EC30) pH-based:	830 mg/kg
aged ACL(LOEC & EC30):	330 mg/kg (the lower of the two ACLs that apply to this soil)
aged ABC:	25 mg/kg
aged SQG(LOEC & EC30):	355 mg/kg which would be rounded off to 350 mg/kg.

$SQG_{(EC50)}$ - Example 1

Site descriptors - urban residential land/public open space use in an old Victorian suburb with a low traffic volume.

Soil descriptors – a sandy acidic soil (pH 5.5, CEC 10) with 1% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$ CEC based:	310 mg/kg
$ACL_{(EC50)}$ pH based:	210 mg/kg
$ACL_{(EC50)}$:	210 mg/kg (the lower of the two ACLs that apply to this soil)
ABC:	10 mg/kg
$SQG_{(EC50)}$:	220 mg/kg

$SQG_{(EC50)}$ - Example 2

Site descriptors - commercial/industrial land use in an old South Australian suburb with a high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$ CEC based:	510 mg/kg
$ACL_{(EC50)}$ pH based:	510 mg/kg
$ACL_{(EC50)}$:	25 mg/kg (the lower of the two ACLs that apply to this soil)
ABC:	25 mg/kg
$SQG_{(EC50)}$:	535 mg/kg

7.8 Reliability of the soil quality guidelines

Based on the criteria established in the methodology for SQG derivation (Schedule B5b), all the Cu SQGs were considered to be of high reliability. This occurred as the toxicity data set easily met the minimum data requirements to use the SSD method and there were normalisation relationships available to account for soil characteristics.

7.9 Comparison with other guidelines

A compilation of SQGs for Cu from a number of jurisdictions is presented in Table 61. These SQGs have a variety of purposes and levels of protection and therefore comparison of the SQGs amongst each other and with the Cu SQGs is problematic. As well, the vast majority of the international SQGs are not soil-specific nor do they account for ageing and leaching. One would therefore expect that the ACLs could be higher than other internationals SQGs. The international guidelines for Cu range from 14 to 1000 mg/kg (added or total Cu) both being from member countries of the European Union (Carlon 2007). The superceded interim urban EIL (NEPC 1999a) for Cu was 100 mg/kg total Cu and therefore in the middle of the range of the international Cu guidelines.

Overall, the superceded interim urban EIL lies in the lower to middle part of the range of ACLs for fresh Cu contamination, while the superceded interim urban EIL lies at the lower third of the range of ACLs for aged contamination.

All of the soil-specific ACL values for urban residential land/public open space use (irrespective of the toxicity data on which they were based) fell within the range of the international residential SQGs, the one exception being the ACLs based on EC50 for soils where the Cu has low bioavailability (that is, high pH and high CEC) which were greater than 1000 mg/kg added Cu.

However, this was a CEC-based ACL and, as stated earlier, when the soil pH is greater than 6, the pH-based ACLs will limit the amount the Cu that can be present in soil. When this was taken into account, all the soil-specific ACL values for residential land use fell within the range of international SQGs.

Similarly, all the ACLs for commercial/industrial land use, with the exception of the aged ACLs based on EC50, fell within the range of international SQGs for Cu. The one exception was the ACL(EC50) values that would permit concentrations nearly twice (that is, 1800 mg/kg added) that of the collated international limits (that is, 1000 mg/kg). However, in soils with a pH above 6, the pH-based ACL will limit the amount of Cu that is permitted in soil and thus all the ACLs for commercial/industrial land use fell within the range of international SQGs.

The Cu $ACL_{(NOEC \& EC10)}$ values in freshly contaminated urban residential/public open space soils (which should theoretically protect 80% of species) ranged from 20 to 250 mg/kg (added Cu) (Table 53). The most suitable comparison with these values is with the limits recommended by the EC Cu ecological risk assessment which used NOEC and EC10 data and should theoretically protect 95% of species. These values range from 20 to 173 mg/kg added Cu. The limits derived by these two processes are very similar.

Table 61. Soil quality guidelines for copper (Cu) from international jurisdictions.

Name of Cu limit	Numerical value of the limit (mg/kg)
Dutch target value[1]	36 (added Cu)
Dutch intervention level[1]	190 (added Cu)
Canadian SQG (residential)[2]	63 (total Cu)
Canadian SQG (commercial and industrial)[2]	91 (total Cu)
Eco-SSL plants[3]	70 (total Cu)
Eco-SSL soil invertebrates[3]	80 (total Cu)
Eco-SSL avian[3]	28 (total Cu)
Eco-SSL mammalian[3]	49 (total Cu)
EU minimal risk values (residential)[4]	14 – 70 (added and total Cu)
EU warning risk values (residential)[4]	100 – 500 (added and total Cu)
EU potential risk values (residential)[4]	100 – 1000 (added and total Cu)
EU Cu ecological risk assessment[5]	26-176[6] (added Cu)

1 = VROM 2000
2 = CCME 1999e, & 2006 and <http://ceqg-rcqe.ccme.ca/>
3 = < http://www.epa.gov/ecotox/ecossl/>
4 = Carlon 2007
5 = EC 2008a.

8 Lead

8.1 Lead compounds considered

The following compounds were considered in deriving the SQGs for lead (Pb):

- lead metal (CAS No. 7439-92-1)
- lead oxide (CAS Nos 1317-36-8)
- lead tetroxide (CAS No. 1314-41-6)
- dibasic lead phthalate (CAS No: 69011-06-9)
- basic lead sulphate (CAS No: 12036-76-9)
- tribasic lead sulphate (CAS No: 12202-17-4)
- tetrabasic lead sulphate (CAS No: 12065-90-6)
- neutral lead stearate (CAS No: 1072-35-1)
- dibasic lead stearate (CAS No: 12578-12-0)
- dibasic lead phosphite (CAS No: 12141-20-7)
- polybasic lead fumarate (CAS No: 90268-59-0)
- basic lead carbonate (CAS No: 1319-46-6)
- basic lead sulphite (CAS No: 62229-08-7).

8.2 Exposure pathway assessment

If the logarithm of the Kd (log Kd) of an inorganic contaminant is less than three then it is considered to have the potential to leach to groundwater (Schedule B5b). The log Kd reported by Commentuijn et al. (2000) for Pb was 3.28 L/kg, therefore there is little potential for Pb to leach to groundwater. If this exposure pathway was considered important at a site, then the methodology for SQG derivation advocates that this be addressed on a site-specific basis as appropriate (Schedule B5b).

The bioconcentration, bioaccumulation and biomagnification of Pb in aquatic ecosystems have received considerable attention. There has also been considerable attention to bioconcentration in terrestrial ecosystems but the biomagnification work has been more limited and often restricted to only examining transfer from food to consumer and not subsequent steps up food chains. One hundred and one terrestrial bioaccumulation factor (BAF) values for Pb have been published (LDA 2008) and these range from 0.00 to 6.86 with a median value of 0.1. kgdw/kgww (where dw = dry weight and ww = wet weight). T he EU ecological risk assessment for Pb (LDA 2008) followed the EC technical guidance document (EC 1996) which applies assessment factors to the lowest NOEC for oral exposure of birds and mammals to account for the potential of Pb to biomagnify. However, using this method led to the derivation of limits that were below the concentrations found in control foods (that is, food that would occur in soils with background concentrations of Pb). These limits therefore imply that food (animal or plant) grown in soils with background concentrations pose a risk, which is not consistent with real-world experience. They therefore used a SSD method to determine the predicted no effect concentration (PNEC) for oral exposure of birds and mammals and obtained a soil limit of 491 mg/kg. This value was higher than the limit based on direct exposure of soil organisms of 333 mg/kg.

Thus, it is apparent that Pb does not pose a biomagnification risk to terrestrial ecosystems. This finding is consistent with the findings for aquatic ecosystems that Pb does not biomagnify (Eisler 1988; Suedel et al. 1994; Demayo et al. 1982; Vighi 1981; Lu et al. 1975 & Henney et al. 1991) and is the conclusion reached by the EC Pb ecological risk assessment (LDA 2008). Therefore, only direct toxic effects to soil organisms were considered in the derivation of the SQGs.

8.3 Toxicity data

All the available Pb toxicity data were reported with both the total concentration and ambient background concentration, therefore the data could be converted to added concentations. A total of ninety-six toxicity data were available for Pb. These were for eight plant species, five species of soil invertebrates and six microbial processes (Table 62). Thus, this met the minimum data requirements recommended by Heemsbergen et al. (2008) to use the BurrliOZ SSD method (Campbell et al. 2000). Table 62 shows the geometric means of toxicity values of each species or soil microbial process that were used to derive the SQGs for Pb. The raw toxicity data used to generate the species geometric means are presented in Appendix G. In the vaxt majority of cases the geometric means of the toxicity data increase from NOEC or EC10 to LOEC or EC30 to EC50 values. However, for *F. candida*, *Raphanus sativa, A. sativa, P. tedea* and *L. sativa* the EC50 values were lower than the LOEC and EC30 data. This reflects the fact that the Pb toxicity data were not normalised for soil properties and the toxicity tests were conducted in soils with a variety of physicochemical properties.

In order to maximise the use of the available toxicity data, conversion factors recommended by in Schedule B5b to permit the inter-conversion of NOEC, LOEC, EC50, EC30 and EC10 data were used (Table 17).

Table 62. Geometric means of the toxicity of lead (Pb) (expressed in terms of added Pb) to soil invertebrates, plants and soil microbial processes.

Test species		Geometric mean (mg/kg)		
Common name	**Scientific name**	**NOEC or EC10**	**LOEC or EC30**	**EC50**
		Invertebrates		
Earthworm	*Dendrobaena rubida*	129	194	387
Earthworm	*E. andrei*	-	1500	3410
Earthworm	*E. fetida*	761	2026	3829
Earthworm	*L. rubellus*	1000	1500	3000
Springtail	*F. candida*	1797	3749	1866
		Microbial processes		
Soil process	ATP	-	-	3018
Soil process	Denitrification	250	500	750
Soil process	Nitrification	337	505	1010
Soil process	N-mineralisation	447	1095	1342
Soil process	Respiration	655	982	1964
Soil process	Substrate induced respiration	1733	2600	5200
		Plants		
Radish	*Raphanus sativus*	100	500	300
Oat	*A. sativa*	100	500	300
Barley	*H. vulgare*	50	250	1270
Red spruce	*Picea rubens*	141	212	1228
Loblolly pine	*Pinus taeda*	546	819	659
Lettuce	*Latuca sativa*	125	188	174
Wheat	*T. aestivum*	250	500	750
Maize	*Z. mays*	100	150	300

8.4 Normalisation relationships

Only two normalisation relationships have been developed for Pb. One models the uptake of Pb by spring wheat (*T. aesitivum*) (Nan et al., 2002) while the other models Pb toxicity to lettuce (*L. sativa*) (Hamon et al. 2003). The toxicity normalisation relationship is presented below:

$$EC50 = 23\ pH + 171\ \text{clay content (\%)} - 40 \qquad (r^2 = 0.84) \qquad \textit{(equation 8)}$$

However, while the above relationship is based on ten toxicity data, they were only tested in five soils. This combined with the fact that the relationship was not validated which severely limits its applicability. The EU ecological risk assessment for Pb (LDA 2008) stated that there is no relationship between soil pH and Pb toxicity. However, they did not make any statement on whether there are relationships between Pb toxicity and other soil physicochemical properties. This was examined as part of the current study. Relationships between the logarithm of NOEC and/or EC10 data and soil pH, log organic matter content (%), log organic carbon content (%), log clay content (%) and log cation exchange capacity (CEC) for all toxicity data combined, for plants only, for invertebrates only and for soil microbial processes only were determined (data not shown). Normalisation relationships were only derived using NOEC and EC10 data as there were considerably more of these data than LOEC and EC30 or EC50 data. Only the relationship between 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 ($r^2 = 0.56$).

Normalisation relationships that explain such a low percentage of the variation (that is, < 60%) are not usually used to normalise toxicity data as they do not account for sufficient of the variability caused by the soil (Warne et al. 2008b). The vast majority of the relationships derived explained less than 10% of the variation in toxicity data and only three could explain more than 10%. Thus there are no useful normalisation relationships available for Pb. Therefore, the toxicity data was not normalised to the Australian reference soil, nor were soil-specific SQGs derived.

8.5 Sensitivity of organisms to lead

The SSD for the Pb NOEC toxicity data is presented in Figure 8. There were only toxicity data for 19 different species/microbial processes and the available data have not been normalised; therefore, the distribution reflects the variability in sensitivity of the organisms and the effect of soil properties. There were insufficient data to make a robust assessment of the relative sensitivity of the groups of organisms. However, the distributions of all three types of organisms overlap, so it was considered appropriate to use all the toxicity data to derive the SQGs.

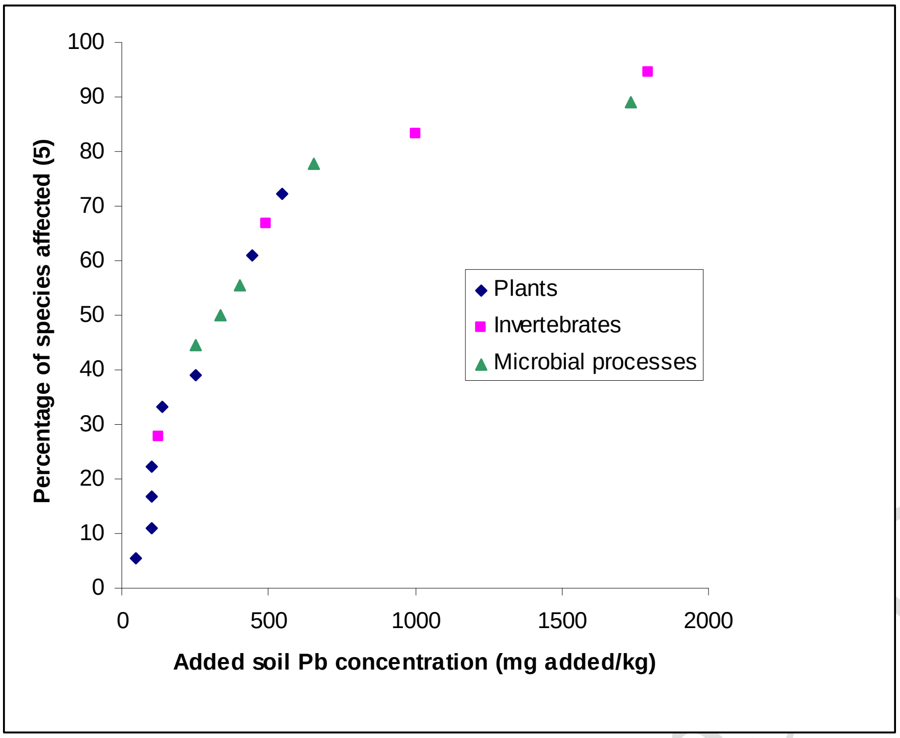


Figure 8. The species sensitivity distribution of fresh lead (Pb) contamination (plotted as a cumulative frequency of the Pb NOEC toxicity data against soil Pb concentration) for soil invertebrates, plants and microbial processes.

8.6 Calculation of soil quality guidelines for fresh lead contamination

There were NOEC and EC10, LOEC and EC30, and EC50 Pb toxicity data. Therefore ACLs and SQGs could be derived using each of these datasets. These were generated using the same general methods as Cu.

8.6.1 Calculation of soil quality guidelines for fresh lead contamination based on NOEC and 10% effect concentration toxicity data

8.6.1.1 Calculation of soil-specific added contaminant limits

There were no normalisation relationships available for Pb and therefore the NOEC and EC10 toxicity data were not normalised, nor could soil-specific ACL values could be derived. The single numerical output from the SSD analysis for each land use became the generic (not soil-specific) ACL for that land use and these are presented in Table 63.

Table 63. Generic ACL (mg/kg) values based on NOEC and 10% effect concentration toxicity data (EC10) for fresh lead (Pb) contamination in soil with various land uses.

Land use	$ACL_{(NOEC\ \&\ EC10)}$ (mg/kg)
National park/area with high ecological value	40
Urban residential/public open space	130
Commercial/industrial	220

8.6.1.2 Calculation of ambient background concentration values

For sites with no history of contamination, the method of Hamon et al. (2004) is recommended to estimate the ABC. The equation to predict the Pb ABC is

$$\log \text{Pb conc (mg/kg)} = 1.039 \log \text{Fe content (\%)} + 0.118 \qquad \textit{(equation 9)}$$

Examples of the ABC values predicted by this equation are presented in Table 64. Predicted ABC values for Pb range from approximately 0.1 to 30 mg/kg in soils with iron concentrations between 0.1 and 20%.

Table 64. Lead (Pb) ABCs predicted using the method of Hamon et al. (2004) (see equation 9 above).

Fe content (%)	Predicted ABC (mg/kg)
0.1	0.1
0.5	0.6
1	1
2	3
5	7
10	15
15	20
20	30

8.6.1.3 Examples of soil quality guidelines for fresh lead contamination in Australian soils based on no observed effect concentration and 10% effect concentration data

The ABC values for Pb vary with the iron content of the soil. Therefore, it is not possible to present a specific set of $SQGs_{(NOEC \& EC10)}$, rather two examples of the range of SQGs that will be encountered in urban settings are presented.

Example 1

Site descriptors - urban residential land/public open space use in a new suburb (i.e. fresh contamination).

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with a 1% iron content.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:
$ACL_{(NOEC \& EC10)}$: 125 mg/kg
ABC: 1 mg/kg
$SQG_{(NOEC \& EC10)}$: 126 mg/kg which would be rounded off to 125 mg/kg

Example 2

Site descriptors - commercial/industrial land use in a new suburb.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:
$ACL_{(NOEC \& EC10)}$: 220 mg/kg
ABC: 15 mg/kg
$SQG_{(NOEC \& EC10)}$: 235 mg/kg which would be rounded off to 230 mg/kg

8.6.2 Calculation of soil quality guidelines for fresh lead contamination based on LOEC and 30% effect concentration toxicity data and on 50% effect concentration data

8.6.2.1 Calculation of soil-specific added contaminant limits

ACLs based on LOEC and EC30 toxicity data ($ACL_{(LOEC\ \&\ EC30)}$) and based on EC50 data ($ACL_{(EC50)}$) were calculated using the method used to derive the ACL values based on NOEC and EC10 data, the one exception being that in order to maximise the amount of LOEC and EC30 and EC50 data, actual measured NOEC data were used to estimate LOEC, EC30 and EC50 data. This was done using the conversion factors derived by Heemsbergen et al. (2008) and presented in Table 17. The geometric means of the LOEC and EC30 and of the EC50 data for the various species/microbial processes that were used to derive the $ACL_{(LOEC\ \&\ EC30)}$ and $ACL_{(EC50)}$ are presented in Table 62.

The resulting $ACL_{(LOEC\ \&\ EC30)}$ and $ACL_{(EC50)}$ values for the three land uses are presented in Table 65. As expected, these values are larger than the corresponding $ACL_{(NOEC\ \&\ EC10)}$ values. The $ACL_{(EC50)}$ values also generally larger than the $ACL_{(LOEC\ \&\ EC30)}$ values with the exception of the values for national park/area with high ecological value. This occurs because the slope of the SSD for the LOEC and EC30 data is less than that of the EC50 data, the SSDs intersect and the LOEC and EC30 data ends up having larger toxicity values.

Table 65. Generic ACLs (mg/kg) based on LOEC and 30% effect concentration data (EC30) and based on 50% effect concentration data (EC50) values for fresh lead (Pb) contamination in soil with various land uses.

Land use	$ACL_{(LOEC\ \&\ EC30)}$ (mg/kg)	$ACL_{(EC50)}$ (mg/kg)
National park/area with high ecological value	110	60
Urban residential/public open space	270	490
Commercial/industrial	440	890

8.6.2.2 Calculation of ambient background concentration values

The ABC values for Pb were calculated using the Hamon et al. (2004) method as outlined previously.

8.6.2.3 Examples of soil quality guidelines for fresh lead contamination in Australian soils based on no observed effect concentration and 10% effect concentration data

As stated previously, the ABC values for Pb vary with the iron content of the soil. Therefore it is not possible to present a specific set of $SQG_{(LOEC\ \&\ EC30)}$ or $SQG_{(EC50)}$ values. Four examples of SQGs that would apply to aged Pb contamination that represent the range (but not the extremes) of SQGs that would apply to urban residential/public open space and commercial/industrial land uses are presented below.

SQG$_{(LOEC \& EC30)}$ Example 1

Site descriptors - urban residential land/public open space use in a new suburb (that is, fresh contamination).

Soil descriptors – these are not relevant as soil properties are not considered in determining the ACL for Pb.

The resulting ACL$_{(LOEC \& EC30)}$, ABC and SQG$_{(LOEC \& EC30)}$ values are:

ACL$_{(LOEC \& EC30)}$:	270 mg/kg
ABC:	1 mg/kg
SQG$_{(LOEC \& EC30)}$:	271 mg/kg which would be rounded off to 270 mg/kg

SQG$_{(LOEC \& EC30)}$ Example 2

Site descriptors - commercial/industrial land use in a new suburb.

Soil descriptors – these are not relevant as soil properties are not considered in determining the ACL for Pb.

The resulting ACL$_{(LOEC \& EC30)}$, ABC and SQG$_{(LOEC \& EC30)}$ values are:

ACL$_{(LOEC \& EC30)}$:	440 mg/kg
ABC:	15 mg/kg
SQG$_{(LOEC \& EC30)}$:	455 mg/kg which would be rounded off to 450 mg/kg

SQG$_{(EC50)}$ Example 1

Site descriptors - urban residential land/public open space use in a new suburb (that is, fresh contamination).

Soil descriptors – these are not relevant as soil properties are not considered in determining the ACL for Pb.

The resulting ACL$_{(EC50)}$, ABC and SQG$_{(EC50)}$ values are:

ACL$_{(EC50)}$:	490 mg/kg
ABC:	1 mg/kg
SQG$_{(EC50)}$:	491 mg/kg which would be rounded off to 490 mg/kg

SQG$_{(EC50)}$ Example 2

Site descriptors - commercial/industrial land use in a new suburb.

Soil descriptors – these are not relevant as soil properties are not considered in determining the ACL for Pb.

The resulting ACL$_{(EC50)}$, ABC and SQG$_{(EC50)}$ values are:

ACL$_{(EC50)}$:	890 mg/kg
ABC:	15 mg/kg
SQG$_{(EC50)}$:	905 mg/kg which would be rounded off to 900 mg/kg

8.7 Calculation of soil quality guidelines for aged lead contamination

8.7.1 Calculation of an ageing and leaching factor

Smolders et al. (2009) examined the literature and developed ALFs for Pb for a range of different organisms. The resulting ALFs ranged from 1.1 to 43 with a median of 4.2. The value of 4.2, recommended by Smolders et al. (2009), was adopted and used in the EC ecological risk assessment of Pb (LDA 2008). Leaching factors for Pb have been developed for five Australian soils from South Australia which ranged from 0.92 to 2.98 and a median and geometric mean of 1.66 and 1.61 respectively (Stevens et al. 2003).

Given the values of Stevens et al. (2003) only account for leaching and not ageing, it is likely any ALFs for Australian soils would be larger and therefore are likely to be consistent with the ALF of Smolders et al. (2009). An ALF of 4.2 was adopted in this project to calculate the SQGs for aged Pb contamination.

8.7.2 Calculation of soil quality guidelines for aged lead contamination based on NOEC and 10% effect concentration toxicity data

8.7.2.1 Calculation of soil-specific added contaminant limits

The ACL values for aged contamination were calculated in exactly the same manner as those for fresh contamination except that the NOEC and EC10 toxicity data were corrected using the Smolders et al. (2009) ALF of 4.2. The resulting ACL values are presented in Table 66.

Table 66. Generic ACLs (mg/kg) based on NOEC data and 10% effect concentration data (EC10) for aged lead (Pb) contamination in soil with various land uses.

Land use	$ACL_{(NOEC\ \&\ EC10)}$ (mg/kg)
National park/area with high ecological value	170
Urban residential/public open space	530
Commercial/industrial	940

8.7.2.2 Calculation of ambient background concentration values

For aged contaminated sites (that is, the contamination has been in-place for at least 2 years), the methodology (Schedule B5b) recommends using the 25th percentiles of the ABC data for the 'old suburbs' from Olszowy et al. (1995) (see Table 67).

Table 67: Lead (Pb) ABCs based on the 25th percentiles of Pb concentrations in 'old suburbs' (i.e. > 2 years old) from various states of Australia (Olszowy et al. 1995).

Suburb type	25th percentile of Pb ABC values (mg/kg)			
	NSW	QLD	SA	VIC
Old suburb low traffic	100	30	30	35
Old suburb high traffic	160	150	90	70

8.7.2.3 Examples of soil quality guidelines for aged lead contamination in Australian soils based on no observed effect concentration and 10% effect concentration data.

As the ABC values for Pb vary with the geographical location of the site it is not possible to present a single set of $SQG_{(NOEC\ \&\ EC10)}$ values. Instead, two examples of the range of SQGs that will be encountered in urban settings are presented below.

Example 1

Site descriptors - urban residential land/public open space use in an old South Australian suburb (that is, contamination is > 2 years old) with low traffic volume.

Soil descriptors – these are not relevant as soil properties are not considered in determining the ACL for Pb.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:
$ACL_{(NOEC \& EC10)}$: 53 mg/kg
ABC: 30 mg/kg
$SQG_{(NOEC \& EC10)}$: 560 mg/kg

Example 2

Site descriptors - commercial/industrial land use in an old Queensland suburb (that is, contamination is > 2 years old) with high traffic volume.

Soil descriptors – these are not relevant as soil properties are not considered in determining the ACL for Pb.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:
$ACL_{(NOEC \& EC10)}$: 940 mg/kg
ABC: 150 mg/kg
$SQG_{(NOEC \& EC10)}$: 1090 mg/kg which would be rounded off to 1100 mg/kg

8.7.3 Calculation of soil quality guidelines for aged lead contamination based on LOEC and 30% effect concentration toxicity data and on 50% effect concentration data

8.7.3.1 Calculation of added contaminant limits

The $ACL_{(LOEC \& EC30)}$ and $ACL_{(EC50)}$ values for aged Pb contamination were calculated using the method explained earlier, except that the data were multiplied by an ALF of 4.2 (Smolders et al. 2009). The resulting $ACL_{(LOEC \& EC30)}$ and $ACL_{(EC50)}$ values for aged Pb contamination in the three land uses are presented in Table 68. As expected, these values are larger than the corresponding ACLs for fresh Pb contamination (Table 65).

Table 68: Generic ACLs based on LOEC and 30% effect concentration (EC30) toxicity data and based on 50% effect concentration toxicity data (EC50) values for aged lead (Pb) contamination in soil with various land uses.

Land use	$ACL_{(LOEC \& EC30)}$ (mg/kg)	$ACL_{(EC50)}$ (mg/kg)
National park/area with high ecological value	470	250
Urban residential/public open space	1100	2000
Commercial/industrial	1800	3700

8.7.3.2 Calculation of ambient background concentration values

The ABC values for aged Pb contamination were calculated using the method described earlier in this Schedule.

8.7.3.3 *Examples of soil quality guidelines for aged lead contamination in Australian soils based on lowest observed effect concentration and 10% effect concentration data and on 50% effect concentration data.*

Four examples of SQGs that would apply to aged Pb contamination that represent the range (but not the extremes) of SQGs that would apply to urban residential/public open space and commercial/industrial land uses are presented below.

$SQG_{(LOEC \& EC30)}$ Example 1

Site descriptors - urban residential land/public open space use in an old South Australian (that is, contamination is > 2 years old) with low traffic volume.

Soil descriptors – these are not relevant as soil properties are not considered in determining the ACL for Pb.

The resulting $ACL_{(LOEC \& EC30)}$, ABC and $SQG_{(LOEC \& EC30)}$ values are:
$ACL_{(LOEC \& EC30)}$: 1100 mg/kg
ABC: 150 mg/kg
$SQG_{(LOEC \& EC30)}$: 1950 mg/kg

$SQG_{(LOEC \& EC30)}$ Example 2

Site descriptors - commercial/industrial land use in an old Queensland suburb (that is, contamination is > 2 years old) with high traffic volume..

Soil descriptors - these are not relevant as soil properties are not considered in determining the ACL for Pb.

The resulting $ACL_{(LOEC \& EC30)}$, ABC and $SQG_{(LOEC \& EC30)}$ values are:
$ACL_{(LOEC \& EC30)}$: 1800 mg/kg
ABC: 150 mg/kg
$SQG_{(LOEC \& EC30)}$: 1950 mg/kg which would be rounded off to 1900 mg/kg

$SQG_{(EC50)}$ Example 1

Site descriptors - urban residential land/public open space use in an old South Australian (that is, contamination is > 2 years old) with low traffic volume.

Soil descriptors – these are not relevant as soil properties are not considered in determining the ACL for Pb.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:
$ACL_{(EC50)}$: 2000 mg/kg
ABC: 30 mg/kg
$SQG_{(EC50)}$: 2030 mg/kg which would be rounded off to 2000 mg/kg

$SQG_{(EC50)}$ Example 2

Site descriptors - commercial/industrial land use in an old Queensland suburb (that is, contamination is > 2 years old) with high traffic volume.

Soil descriptors - these are not relevant as soil properties are not considered in determining the ACL for Pb.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:
$ACL_{(EC50)}$: 3700 mg/kg
ABC: 150 mg/kg
$SQG_{(EC50)}$: 3850 mg/kg

8.8 Reliability of the soil quality guidelines

The Pb toxicity data set met the minimum data requirements to use the SSD method but there were no suitable normalisation relationships available to account for soil characteristics. Based on the criteria for assessing the reliability of SQGs (Schedule B5b), this means that the Pb SQGs were considered to be of moderate reliability.

8.9 Comparison with other guidelines

A compilation of SQGs for Pb in a number of jurisdictions is presented in Table 69. These SQGs have a variety of purposes and levels of protection and therefore comparison of the values is problematic. The superceded interim urban EIL for Pb was 600 mg/kg total.

The urban residential/public open space ACLs for fresh Pb contamination (irrespective of the type of toxicity data on which they were based) are all lower than the current interim urban EIL.

The aged $ACL_{(NOEC\ \&\ EC10)}$ for urban residential land/public open space use at 530 mg/kg added is lower than the superceded interim urban EIL, while the aged $ACL_{(LOEC\ \&\ EC30)}$ and $ACL_{(EC50)}$ are considerably larger (that is, 1100 and 2000 mg/kg respectively). The $ACL_{(NOEC\ \&\ EC10)}$ for fresh Pb contamination is similar to the Canadian residential SQG and the plant Eco-SSL (Table 69).

The fresh $ACL_{(NOEC\ \&\ EC10)}$, $ACL_{(LOEC\ \&\ EC30)}$ and $ACL_{(EC50)}$ for urban residential land/public open space use correspond to the minimal, warning and potential risk values for residential land use of the EU. The fresh $ACL_{(NOEC\ \&\ EC10)}$ is about 50% larger than the highest minimal risk SQG, but the $ACL_{(LOEC\ \&\ EC30)}$ and $ACL_{(EC50)}$ lie within the range of values for the corresponding EU SQGs.

The best comparison (in terms of the way in which the SQGs were derived) with the ACLs is with the limit derived by the EC ecological risk assessment for Pb (LDA 2008) which also corrected laboratory toxicity data for ageing and leaching. The EC derived a concentration that should protect 95% of terrestrial species of 333 mg/kg added Pb (LDA 2008). If the data and method that were used here (Schedule B5b) were used to calculate the concentration that should protect 95% of species, the value would be 275 mg/kg added Pb — this is slightly more conservative than the EC value.

Table 69. Soil quality guidelines for lead (Pb) in a number of international jurisdictions.

Name of the Pb soil quality guideline	Value of the guidelines (mg/kg)
Canadian SQG (residential)[1]	140 (total Pb)
Canadian SQG (commercial)[1]	260 (total Pb)
Canadian SQG (industrial)[1]	600 (total Pb)
Eco-SSL plants[3]	120 (total Pb)
Eco-SSL soil invertebrates[3]	1700 (total Pb)
Eco-SSL avian[3]	11 (total Pb)
Eco-SSL mammalian[3]	56 (total Pb)
Netherlands (target value)	85 (added Pb)
Netherlands (intervention value)	530 (added Pb)
EU minimal risk values (residential)[4]	25 – 85 (added Pb)
EU warning risk values (residential)	40 – 700 (added Pb)
EU potential risk values (residential)[4]	100 – 700 (added Pb)
EC Pb ecological risk assessment (aged HC5)[5]	333(added Pb)

1 = CCME 1999f,, 2006 and< http://ceqg-rcqe.ccme.ca/>
2 = Carlon 2007
3 = <http://www.epa.gov/ecotox/ecossl/>
4 = Carlon 2007
5 = LDA 2008.

9 Nickel

9.1 Nickel compounds considered

The following salts were considered in deriving SQGs for nickel (Ni):

- nickel metal (CAS No. 7440-02-0)
- nickel sulphate (CAS No. 7786-81-4)
- nickel carbonate (CAS No. 3333-67-3)
- nickel chloride (CAS No. 7718-54-9)
- nickel dinitrate (CAS No. 13138-45-9).

9.2 Exposure pathway assessment

For the leaching to groundwater pathway, adsorption (Kd) is the critical parameter. If the logarithm of the Kd (log Kd) of an inorganic contaminant is less than three then it is considered to have the potential to leach to groundwater (Schedule B5b). The log Kd reported by Commentuijn et al. (2000) for Ni was 2.08 L/kg, therefore there is some potential for Ni to leach to groundwater. If this exposure pathway was considered important for a given site, the methodology for SQG derivation advocates that this be addressed on a site-specific basis as appropriate (Schedule B5b).

The literature assessing the potential for Ni to biomagnify is limited, particularly for terrestrial ecosystems. However, all the available literature suggests that Ni does not biomagnify (Outridge & Schuehammer 1993; Torres & Johnson 2001; Campbell et al. 2005; Muir et al. 2005; Lapointe & Couture 2006). The EC ecological risk assessment for Ni also concluded that Ni did not biomagnify (EC 2008b). Therefore only direct toxic effects were considered in deriving the SQGs for Ni.

9.3 Toxicity data

The raw toxicity data available for Ni are presented in Appendix H. There was a total of 338 data for Ni. There were toxicity data for 11 plants species, six species of invertebrates and 26 microbial processes. The lowest geometric means of the toxicity data for each species and soil process are presented in Tables 70 and 71 respectively. These data exceeded the minimum data requirements to use the BurrliOZ software (Campbell et al. 2000) that are recommended in Schedule B5b. Therefore the SSD approach was used to derive the SQGs for Ni.

Table 70. The lowest geometric mean values of the normalised nickel (Ni) toxicity data for soil invertebrate and plant species.

Test species		Geometric means (mg/kg)		
Common name	**Scientific name**	**NOEC or EC10**	**LOEC or EC30**	**EC50**
Invertebrates				
Earthworm	*E. fetida*	162	245	474
Earthworm	*Eisenia veneta*	103	365	409
Earthworm	*L. rubellus*	407	523	575
Potworm	*Enchytraeus albidus*	134	239	205
Springtail	*F. fimetaria*	210	315	631
Springtail	*F. candida*	235	359	680
Plants				
Alfalfa	*Medicago sativa*	36.4	80.8	87.1
Barley	*H. vulgare*	166.7	250	409
Fenugreek	*Trigonella poenumgraceum*	68.6	109	144
Lettuce	*L. sativa*	52.6	125	154
Maize	*Z. mays*	49.4	94.8	127
Oats	*A. sativa*	55.3	83.9	122
Onion	*Allium cepa*	37.6	59.7	84.5
Perennial ryegrass	*L. perenne*	40.9	50.2	57.1
Radish	*R. sativus*	57.5	65.5	66.8
Spinach	*Spinacia oleracea*	26.9	41.1	47.2
Tomato	*L. esculentum*	94.8	142	238

Table 71. The lowest geometric mean values of the normalised nickel (Ni) toxicity data for soil microbial processes.

Microbial process	Geometric means (mg/kg)		
	NOEC or EC10	LOEC or EC30	EC50
Arylsulfatase	784	1176	1191
Aspergillus clavatus (hyphal growth)	14.9	45.9	91.0
Aspergillus flavus (hyphal growth)	451	586	689
Aspergillus flavipes (hyphal growth)	398	444	475
Aspergillus niger (hyphal growth)	459	545	606
ATP content	75.5	113	392
Gliocladium sp. (hyphal growth)	230	560	1036
Bacillus cereus (colony count)	327	1010	1958
Dehydrogenase	6.8	20.8	85.5
Glucose respiration	79.5	119	238
Glutamate respiration	44.5	191	381
Maize residue respiration	134	201	402
Nitrification	81.3	122	244
N-mineralisation	95.8	144	287
Nocardia rhodochrous (colony count)	203	662	943
Penicillium vermiculatum (hyphal growth)	117	271	460
Phosphotase	524	1347	5715
Protease	75.5	113	392
Proteus vulgaris (colony count)	17.2	88.8	249
Respiration (CO_2 release)	102	2583	4593
Rhizopus stolonifer (hyphal growth)	331	404	459
Rhodotorula rubra (colony count)	283	837	1796
Sacharase	75.5	113	392
Serratia marcescens (colony count)	178	337	395
Trichoderma viride (hyphal growth)	608	686	740
Urease	222	332	879

9.4 Normalisation relationships

Normalisation relationships relating the toxicity of Ni to three soil microbial processes (that is, nitrification, glucose-induced respiration and maize residue mineralisation) were developed by Oorts et al. (2006b). Two normalisation relationships have also been developed for crops (tomato and barley) by Rooney et al. (2007). In addition, the EC Ni ecological risk assessment (EC 2008b) reported Ni normalisation relationships for two soil invertebrates (*F. candida and E. fetida*). All of these relationships were developed for both fresh and aged contamination and are presented in Table 72. No Ni normalisation relationships have been developed for Australian species and/or soils.

The normalisation relationships presented in Table 72 all model EC50 toxicity data, with the exception of the maize residue mineralisation which models EC20 data. Relationships between the logarithm of Ni NOEC and EC10 data and logarithm of CEC were developed as part of this project. Normalisation relationships were developed for (a) all organisms, (b) each group of organisms separately, and (c) each species or microbial process separately. Only CEC was used to develop the normalisation relationships as in all the published relationships for Ni the CEC was the best parameter (Oorts et al. 2006b; Rooney et al. 2007; EC 2008b). Only six normalisation relationships could explain more than 50% of the variation in the toxicity data (i.e., $r^2 > 0.5$) and these are presented in Table 73. The vast majority of the normalisation relationships had r^2 values of < 0.1.

Normalisation relationships are available for a variety of biological end-points based on both NOEC & EC10 data and on EC50 data. The relationships used to normalise the data in the current study were relationships 1, 5 and 9 from Table 72 for glucose-induced respiration, nitrification and tomato and relationships 2, 3, 5, 6 from Table 73 for barley, all invertebrates, maize residue mineralisation and respiration. The relationships with the lowest gradients for each species were selected. The exception to this was the relationship for invertebrates. This was selected as it was based on all invertebrate species and its gradient was only marginally higher than the invertebrate relationship with the lowest gradient. For the species that did not have normalisation relationships, the relationship for the most closely related species was used, or in the case where there were relationships for several related species the relationship with the lowest gradient was used. Thus, all plants species (apart from tomato) were normalised with the EC10 relationship for barley and all the microbial processes without a relationship were normalised with the EC10 relationship for maize residue mineralisation.

Table 72. Normalisation relationships between soil CEC and the toxicity of nickel (Ni) to a variety of soil plant and invertebrate species and soil microbial processes for both fresh and aged contamination. The relationships used to normalise the toxicity data in this project are in bold.

Eqtn no.	Species/soil process	Y parameter	X parameter(s)	Reference
Northern hemisphere relationships[a]				
1	Glucose induced respiration	log EC50 (fresh)	**0.95 log CEC + 1.51** (r^2 = 0.82)	Oorts et al. 2006b
2		log EC50 (aged)	1.34 log CEC + 1.38 (r^2 = 0.92)	Oorts et al. 2006b
3	Maize residue mineralisation	log EC20 (fresh)	0.86 log CEC + 1.48 (r^2 = 0.55)	Oorts et al. 2006b
4		log EC20 (aged)	1.22 log CEC + 1.37 (r^2 = 0.72)	Oorts et al. 2006b
5	Nitrification	log EC50 (fresh)	**0.79 log CEC + 1.44** (r^2 = 0.69)	Oorts et al. 2006b
6		log EC50 (aged)	1.00 log CEC + 1.42 (r^2 = 0.60)	Oorts et al. 2006b
7	Barley root elongation	log EC50 (fresh)	0.90 log CEC + 1.60 (r^2 = 0.92)	Rooney et al. 2007
8		log EC50 (aged)	1.12 log CEC + 1.57 (r^2 = 0.83)	Rooney et al. 2007
9	Tomato shoot yield	log EC50 (fresh)	**1.06 log CEC + 1.09** (r^2 = 0.77)	Rooney et al. 2007
10		log EC50 (aged)	1.27 log CEC + 1.06 (r^2 = 0.67)	Rooney et al. 2007
11	*F. candida* (collembola)	log EC50 (fresh)	0.97 log CEC + 1.71 (r^2 = 0.84)	EC 2008b
12		log EC50 (aged)	1.17 log CEC + 1.70 (r^2 = 0.71)	EC 2008b
13	*E. fetida* (earthworm)	log EC50 (fresh)	0.72 log CEC + 1.79 (r^2 = 0.74)	EC 2008b
14		log EC50 (aged)	0.95 log CEC + 1.76 (r^2 = 0.72)	EC 2008b

a = all the CEC measurements were made using the silver thiourea method (Chhabra et al. 1975).

Table 73. The normalisation relationships for nickel (Ni) that could explain more than 50% of the variation in the NOEC and 10% effect concentration (EC10) data. The x and y parameters in each equation are the logarithms of the CEC and of the NOEC or EC10 toxicity data, respectively. The relationships used to normalise the toxicity data in this project are in bold.

Equation no.	Species and endpoint	X parameter(s)[a]
1	Tomato (shoot yield)	1.068 x + 0.908 (r^2 = 0.76)
2	Barley (root elongation)	**0.87 x + 1.35** (r^2 = 0.86**)**
3	All invertebrates (mixed endpoints)	**0.78 x + 1.51** (r^2 = 0.56)
4	Glucose respiration	1.42 x – 0.38 (r^2 = 0.58)
5	Maize residue mineralisation	**0.67 x + 1.45** (r^2 = 0.53)
6	Respiration	**2.37 x – 0.36** (r^2 = 0.92)

a = all CEC measurements were made using the silver thiourea method (Chhabra et al. 1975).

9.5 Sensitivity of organisms to nickel

Figure 9 shows the SSD (that is, the cumulative distribution of the geometric means of normalised NOEC and EC10 toxicity values) for the species used to derive the Ni SQGs. While there is an abundance of terrestrial toxicity data for Ni, the majority are for microbial processes and microbial enzymes with only small amounts of data for plants and invertebrates. There does not appear to be any difference in the sensitivity of microbial processes and both plants and invertebrates. However, the distribution of the sensitivities of the plants and invertebrates only just overlap. Nonetheless, there are no marked differences in the sensitivity of the three groups of organisms and therefore all the available toxicity data were used to derive the Ni SQGs.

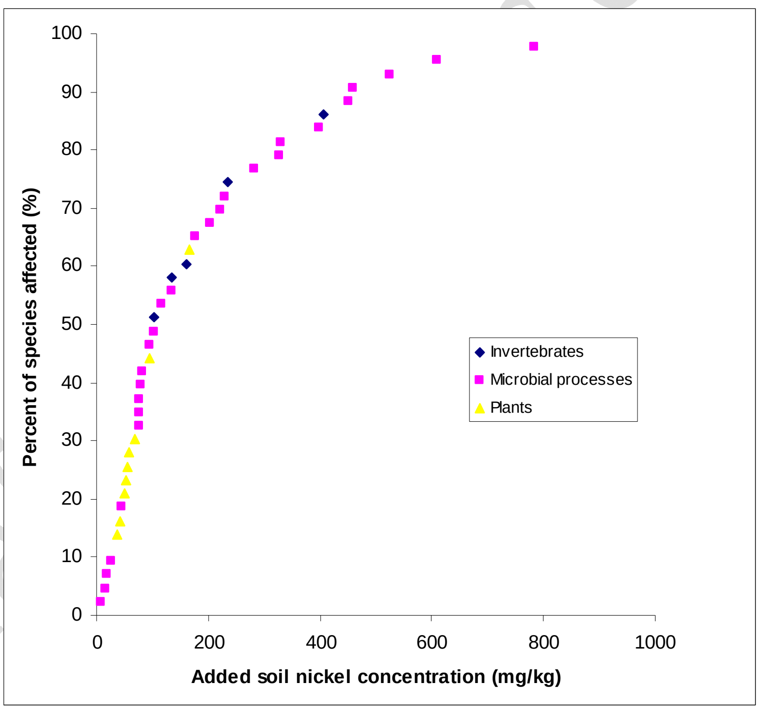


Figure 9. The SSD of normalised NOEC and 10% effect concentration (EC10) toxicity data for fresh nickel (Ni) contamination against soil Ni concentration for soil invertebrates, plants and microbial processes.

9.6 Calculation of soil quality guidelines for fresh nickel contamination

Soil quality guidelines were derived using three different sets of toxicity data (that is, NOEC and EC10, LOEC and EC30, and EC50 data) as part of this study.

9.6.1 Calculation of soil quality guidelines for fresh nickel contamination based on no observed effect concentration and 10% effect concentration toxicity data

9.6.1.1 Calculation of soil-specific added contaminant limits

All the toxicity data was normalised as set out earlier. The generic $ACL_{(NOEC\ \&\ EC10)}$ values generated for fresh Ni contamination for the three land uses are presented in Table 74.

Table 74. Generic ACLS for fresh nickel (Ni) contamination based on NOEC and 10% effect concentration (EC10) toxicity data for various land uses.

Land use	Generic added contaminant limit (mg added/kg)
National park/area with high ecological value	6
Residential urban/public open space	50
Commercial/industrial	95

The normalisation equations were then used to calculate soil-specific ACL values at a range of CEC values. Then the lowest ACL at each CEC value was adopted as the soil-specific ACL (Table 75).

Table 75. The soil-specific ACLs (mg/kg) at a range of cation exchange capacities for fresh nickel (Ni) contamination based on NOEC and 10% effect concentration (EC10) toxicity data.

Land use	Cation exchange capacities ($cmol_c/kg$)[a]					
	5	10	20	30	40	60
National park/area with high ecological value	1	6	9	10	15	20
Residential urban/public open space	10	50	80	110	130	170
Commercial/industrial	20	95	150	200	240	310

a = all CEC measurements were made using the silver thiourea method (Chhabra et al. 1975).

9.6.1.2 Calculation of ambient background concentration values

For sites with no history of Ni contamination, the method of Hamon et al. (2004) is recommended in Schedule B5b to estimate the ABC. The equation to predict the ABC for Ni is

$$\log \text{Ni conc (mg/kg)} = 0.702 \log \text{Fe content (\%)} + 0.834 \qquad \textit{(equation 10)}$$

Examples of the ABC values predicted by this equation are presented in Table 76.

Table 76. ABCs for nickel (Ni) predicted using the equation from method of Hamon et al. (2004) (equation 10 above).

Fe content (%)	Predicted ABC (mg/kg)
0.1	1
0.5	4
1	7
2	10
5	20
10	35
15	45
20	55

Predicted ABC values for Ni range from approximately 1.4 to 55 mg/kg in soils with iron contents between 0.1 and 20%.

9.6.1.3 Examples of soil quality guidelines for fresh nickel contamination in Australian soils based on no observed effect concentration and 10% effect concentration data

To calculate the Ni $SQG_{(NOEC \& EC10)}$ values, the ABC value is added to the $ACL_{(NOEC \& EC10)}$. ABC values vary with soil type. Therefore, it is not possible to present a single set of $SQG_{(NOEC \& EC10)}$ values. Thus, two examples of Ni $SQG_{(NOEC \& EC10)}$ values for urban contaminated soils are provided below. These examples would be at the low and high end of the range of SQG values (but not the extreme values) generated for Australian soils.

Example 1

Site descriptors – urban residential land/public open space use in a new suburb (that is, fresh contamination).

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with 1% iron content.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:
$ACL_{(NOEC \& EC10)}$: 50 mg/kg
ABC: 7 mg/kg
$SQG_{(NOEC \& EC10)}$: 57 mg/kg which would be rounded off to 55 mg/kg

Example 2

Site descriptors – commercial/industrial land use in a new suburb.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(NOEC \& EC10)}$ABC and $SQG_{(NOEC \& EC10)}$ values are:
$ACL_{(NOEC \& EC10)}$: 240 mg/kg
ABC: 35 mg/kg
$SQG_{(NOEC \& EC10)}$: 275 mg/kg which would be rounded off to 270 mg/kg

9.6.2 Calculation of soil quality guidelines for fresh nickel contamination based on LOEC and 30% effect concentration toxicity data and on 50% effect concentration data

9.6.2.1 Calculation of soil-specific added contaminant limits

To maximise the data available to generate the $ACL_{(LOEC \& EC30)}$ and $ACL_{(EC50)}$ the available toxicity data were converted to the appropriate measure of toxicity using the conversion factors recommended in Schedule B5b and presented in Table 17. As there were normalisation equations available, soil-specific ACLs could be generated. The $ACL_{(LOEC \& EC30)}$ and $ACL_{(EC50)}$ values were calculated using the same method as that for the corresponding values for Cu and Pb and are presented in Table 77.

Table 77. The soil-specific ACLs (mg/kg) at a range of cation exchange capacities for fresh nickel (Ni) contamination based on LOEC and 30% effect concentration (EC30) toxicity data and based on 50% effect concentration (EC50) toxicity data.

Land use	Cation exchange capacities ($cmol_c$/kg)[a]					
	5	10	20	30	40	60
	Based on LOEC and EC30 data					
National park/area with high ecological value	1	7	10	15	15	25
Residential urban/public open space	10	50	85	110	130	170
Commercial/industrial	20	100	170	220	260	350
	Based on EC50 data					
National park/area with high ecological value	5	25	40	55	65	90
Residential urban/public open space	30	160	250	330	400	520
Commercial/industrial	55	280	450	590	710	940

a = all CEC measurements were made using the silver thiourea method (Chhabra et al. 1975).

9.6.2.2 Calculation of ambient background concentration values

The ABC values for Ni were calculated using the method previously set out, and the values presented in Table 76.

9.6.2.3 Examples of soil quality guidelines for fresh nickel contamination in Australian soils based on no observed effect concentration and 10% effect concentration data

To calculate the Ni $SQG_{(LOEC \& EC30)}$ and the $SQG_{(EC50)}$ values, the ABC value is added to the corresponding ACL values. ABC values and Ni ACL values vary with soil type. Therefore it is not possible to present a single set of $SQG_{(LOEC \& EC30)}$ or $SQG_{(EC50)}$ values. Thus, two examples of Ni $SQG_{(LOEC \& EC30)}$ and two examples for Ni $SQG_{(EC50)}$ are provided below. These examples would be at the low and high end of the range of SQG values (but not the extreme values) generated for Australian soils.

$SQG_{(LOEC\ \&\ EC30)}$ Example 1

Site descriptors - urban residential land/public open space use in a new suburb (that is, fresh contamination).

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with 1% iron content.

The resulting $ACL_{(LOEC\ \&\ EC30)}$, ABC and $SQG_{(LOEC\ \&\ EC30)}$ values are:

$ACL_{(LOEC\ \&\ EC30)}$:	50 mg/kg
ABC:	7 mg/kg
$SQG_{(LOEC\ \&\ EC30)}$:	57 mg/kg which would be rounded off to 55 mg/kg

$SQG_{(LOEC\ \&\ EC30)}$ Example 2

Site descriptors – commercial/industrial land use in a new suburb.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(LOEC\ \&\ EC30)}$, ABC and $SQG_{(LOEC\ \&\ EC30)}$ values are:

$ACL_{(LOEC\ \&\ EC30)}$:	260 mg/kg
ABC:	35 mg/kg
$SQG_{(LOEC\ \&\ EC30)}$:	295 mg/kg which would be rounded off to 290 mg/kg

$SQG_{(EC50)}$ Example 1

Site descriptors - urban residential land/public open space use in a new suburb (that is, fresh contamination).

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with 1% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$:	160 mg/kg
ABC:	7 mg/kg
$SQG_{(EC50)}$:	167 mg/kg which would be rounded off to 170 mg/kg

$SQG_{(EC50)}$ Example 2

Site descriptors – commercial/industrial land use in a new suburb.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$:	710 mg/kg
ABC:	35 mg/kg
$SQG_{(EC50)}$:	745 mg/kg which would be rounded off to 750 mg/kg

9.7 Calculation of soil quality guidelines for aged nickel contamination

9.7.1 Calculation of ageing and leaching factors for nickel

Smolders et al. (2009) state that based on an extensive review of the literature the ALF for Ni is a function of soil pH (measured in 0.01 M calcium chloride solution) and ranges between 1 and 3.5. Further detail on this relationship is provided in the EC ecological risk assessment report for Ni (EC 2008b). The relationship between the ALF and soil pH is:

$$ALF = 1 + \exp(1.4(\text{soil pH} - 7.0) \qquad \textit{(equation 11)}$$

However, using this equation indicates that the ALF will rapidly increase after a soil pH of 7.5 to values considerably higher than 3.5 (Table 78).

Table 78. ALF values for nickel (Ni) at various soil pH values. The ALF values were derived using the relationship from the European Commission ecological risk assessment for Ni (EC 2008b).

Soil pH ($CaCl_2$)	ALF
5	1.07
6	1.25
7	2.00
7.5	3.01
8	5.06
8.5	9.17
9.0	17.45

The above ALF values were calculated after a maximum of 1.5 years ageing in the field, therefore in most 'aged' Australian sites the ALFs would be larger. However, there is no information available that would permit estimates of how much larger the ALFs would be and therefore the above ALF values were used to calculate the Ni SQGs.

9.7.2 Use of ageing and leaching factors in the methodology

There are two possible approaches to incorporating the relationship between ALF and soil pH into the methodology for deriving SQGs. In the first, a soil pH that is reasonably representative or protective of the majority of Australian soils is selected and the corresponding ALF is then used to calculate the aged SQGs. The resulting SQGs would be protective of all aged soils with a pH higher than the selected pH, but would not provide the same level of protection to soils with lower soil pH. Such soils would have to proceed to further desktop analysis by using the ALF-pH relationship to determine the appropriate ALF for that soil and then apply that to the fresh contamination SQGs. To maximise the utility of this approach and minimise the number of sites that would require the additional analysis, the selected soil pH would have to be low, perhaps as low as 5. This would result in an ALF of 1.07 and with such a small increase in the resulting aged SQGs that it is doubtful that it would be of any real benefit.

The second approach would be to fully adopt the ALF-pH relationship into the methodology for deriving SQGs, where the pH of the site would need to be determined and then the appropriate ALF calculated for the site and applied to the toxicity data to generate the aged contamination ACLs and thence the aged SQGs. While the latter is more complex, the benefits of having the most scientifically defensible ACLs and SQGs outweigh this. It is recommended that SQGs are derived by multiplying fresh (non-aged and non-leached) toxicity data by the ALF determined using the ALF-pH relationship (see equation 11).

9.7.3 Calculation of soil quality guidelines for aged nickel contamination based NOEC and 10% effect concentration toxicity data

9.7.3.1 Calculation of soil-specific added contaminant limits

The aged $SQG_{(NOEC \,\&\, EC10)}$ values for Ni were calculated using the same methodology as that used for the $SQG_{(NOEC \,\&\, EC10)}$ values for fresh Ni contamination with two exceptions. These were (i) that the "fresh" toxicity data were corrected using the Ni ALFs (equation 11) and (ii) the ABCs were the 25th percentile values for old suburbs from Olszowy et al. (1995). The resulting $ACL_{(NOEC \,\&\, EC10)}$ values for aged Ni contamination are presented in Table 79.

Table 79. The soil-specific ACLs (mg/kg) at a range of cation exchange capacities for aged nickel (Ni) contamination based on NOEC and 10% effect concentration (EC10) toxicity data.

Land use	Cation exchange capacities ($cmol_c$/kg)[a]					
	5	10	20	30	40	60
National park/area with high ecological value	2	9	15	20	20	30
Residential urban/public open space	15	85	140	180	220	290
Commercial/industrial	30	160	250	330	400	530

a = all CEC measurements were made using the silver thiourea method (Chhabra et al. 1975).

9.7.3.2 Calculation of ambient background concentration values

For aged contaminated sites (that is, the contamination has been in place for at least 2 years) Heemsbergen et al. (2008) recommends using the 25th percentiles of the ABC data for 'old suburbs' in Olszowy et al. (1995) (see Table 80). The Olszowy et al. (1995) data is derived from soils low in geogenic Ni and, through utilising low ABCs, could create low SQGs in some areas with naturally high background Ni concentrations. This problem could be overcome in areas with elevated soil Ni by using measured ABC values or using the method of Hamon et al. (2004).

Table 80. Nickel (Ni) ABCs based on the 25 percentiles of Ni concentrations in 'old suburbs' (i.e. > 2 years old) from various states of Australia (Olszowy et al. 1995).

Suburb type	25th percentile of Ni ABC values (mg/kg)			
	NSW	QLD	SA	VIC
Old suburb low traffic	5	5	6	5
Old suburb high traffic	5	4	6	10

9.7.3.3 Examples of soil quality guidelines for aged nickel contamination in Australian soils based on no observed effect concentration and 10% effect concentration data

To calculate the aged Ni $SQG_{(NOEC\ \&\ EC10)}$ values , the ABC value is added to the ACL. Ambient background concentration values vary with soil type, region and history of exposure to contamination. Therefore, it is not possible to present a single set of $SQG_{(NOEC\ \&\ EC10)}$ values. Thus, two examples of Ni $SQG_{(NOEC\ \&\ EC10)}$ values are presented below. These examples would be at the low and high end of the range of SQG values (but not the extreme values) generated for Australian soils.

Example 1

Site descriptors - urban residential land/public open space use in an old Queensland suburb (that is, aged contamination) with low traffic volume.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with a 1% iron content.

The resulting $ACL_{(NOEC\ \&\ EC10)}$, ABC and $SQG_{(NOEC\ \&\ EC10)}$ values are:
$ACL_{(NOEC\ \&\ EC10)}$: 85 mg/kg
ABC: 5 mg/kg
$SQG_{(NOEC\ \&\ EC10)}$: 90 mg/kg

Example 2

Site descriptors – commercial/industrial land use in an old Victorian suburb (that is, aged contamination) with high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(NOEC\ \&\ EC10)}$, ABC and $SQG_{(NOEC\ \&\ EC10)}$ values are:
$ACL_{(NOEC\ \&\ EC10)}$: 400 mg/kg
ABC: 10 mg/kg
$SQG_{(NOEC\ \&\ EC10)}$: 410 mg/kg which would be rounded off to 400 mg/kg

9.7.4 Calculation of soil quality guidelines for aged nickel contamination based on LOEC and 30% effect concentration toxicity data and on 50% effect concentration data

9.7.4.1 Calculation of soil-specific added contaminant limits

Soil-specific aged Ni ACL values based on LOEC and EC30 and on EC50 data were calculated using the method previously set out, except the type of toxicity data used was different. The resulting ACLs are presented in Table 81.

Table 81. The soil-specific ACLs at a range of cation exchange capacities for aged nickel (Ni) contamination based on lowest observed effect concentration (LOEC) and 30% effect concentration (EC30) toxicity data and based on 50% effect concentration (EC50) toxicity data.

Land use	Cation exchange capacities ($cmol_c$/kg)[a]					
	5	**10**	**20**	**30**	**40**	**60**
	Based on LOEC and EC30 data					
National park/area with high ecological value	5	30	45	60	70	95
Urban residential/public open space	30	170	270	350	420	560
Commercial/industrial	55	290	460	600	730	960
	Based on EC50 data					
National park/area with high ecological value	10	65	100	130	160	210
Urban residential/public open space	55	270	440	570	700	910
Commercial/industrial	90	460	730	960	1200	1500

a = all CEC measurements were made using the silver thiourea method (Chhabra et al. 1975).

9.7.4.2 Calculation of ambient background concentration values

The ABC values used for aged Ni were obtained from Table 80.

9.7.4.3 Examples of soil quality guidelines for fresh nickel contamination in Australian soils based on no observed effect concentration and 10% effect concentration data

Ambient background concentration values for Ni vary with soil type as do the Ni ACL values. Therefore, it is not possible to present a single set of $SQG_{(LOEC\ \&\ EC30)}$ or $SQG_{(EC50)}$ values. Thus, two examples of Ni $SQG_{(LOEC\ \&\ EC30)}$ values and two examples for Ni $SQG_{(EC50)}$ values are provided below. These examples would be at the low and high end of the range of SQG values (but not the extreme values) generated for Australian soils.

$SQG_{(LOEC\ \&\ EC30)}$ Example 1

Site descriptors - urban residential land/public open space use in an old Queensland suburb with high traffic volume (that is, aged contamination).

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with 1% iron content.

The resulting $ACL_{(LOEC\ \&\ EC30)}$, ABC and $SQG_{(LOEC\ \&\ EC30)}$ values are:

$ACL_{(LOEC\ \&\ EC30)}$:	170 mg/kg
ABC:	4 mg/kg
$SQG_{(LOEC\ \&\ EC30)}$:	174 mg/kg which would be rounded off to 170 mg/kg.

$SQG_{(LOEC\ \&\ EC30)}$ Example 2

Site descriptors – commercial/industrial land use in an old Victorian suburb with high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(LOEC\ \&\ EC30)}$, ABC and $SQG_{(LOEC\ \&\ EC30)}$ values are:

$ACL_{(LOEC\ \&\ EC30)}$:	730 mg/kg
ABC:	10 mg/kg
$SQG_{(LOEC\ \&\ EC30)}$:	740 mg/kg which would be rounded off to 700 mg/kg.

$SQG_{(EC50)}$ Example 1

Site descriptors - urban residential land/public open space use in an old Queensland suburb with high traffic volume (that is, aged contamination).

Soil descriptors – a sandy acidic soil (pH 5, CEC 10) with a 1% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$:	270 mg/kg
ABC:	4 mg/kg
$SQG_{(EC50)}$:	274 mg/kg which would be rounded off to 270 mg/kg.

$SQG_{(EC50)}$ Example 2

Site descriptors – commercial/industrial land use in an old Victorian suburb with high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40) with a 10% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$:	1200 mg/kg
ABC:	10 mg/kg
$SQG_{(EC50)}$:	1210 mg/kg which would be rounded off to 1200 mg/kg.

9.8 Reliability of the soil quality guidelines

The SQGs for Ni were considered to be of high reliability as the toxicity data set met the minimum data requirements to use a SSD method and there were normalisation relationships available to account for soil characteristics (Schedule B5b).

9.9 Comparison with other guidelines

Soil quality guidelines for Ni in a number of international jurisdictions are presented in Table 82. These SQGs have a variety of purposes and levels of protection and therefore a comparison of the values is problematic. The SQGs for Ni range from 24 to 500 mg/kg added and total Ni with both of these values coming from countries within the EU. The superceded interim urban EIL for Ni (NEPC 1999a) was 60 mg/kg total Ni.

There are also four health-based investigation level (HIL) values that range from 400 to 4000 mg/kg total Ni (see Schedule B1). The urban residential/public open space ACLs based on NOEC and EC10, LOEC and EC30, and EC50 data for fresh Ni contamination range from 10–170, 10–170, and 30 to 520 mg/kg added Ni respectively. These correspond to the 'minimal risk', 'warning risk' and the 'potential risk' values of EU member countries and the values are very similar. The urban residential/public open space ACLs based on NOEC and EC10, LOEC and EC30, and EC50 data for aged Ni contamination range from 15 to 290, 30 to 560, and 55 to 910 mg/kg added Ni respectively. These limits permit higher concentrations than in any of the other jurisdictions, but this is not suprising as the other jurisdictions do not account for ageing or leaching nor do they take into account the bioavailability in different soils.

The most meaningful comparisons can be made between the SQGs and the concentrations that would protect 95% of species based on NOEC and EC10 data that were derived in the EC ecological risk assessment for Ni (EC 2008b). These values ranged from 8.3 to 188.7 mg/kg added Ni for soils with CEC values ranging from 2.4 to 36 $cmol_c$/kg (EC 2008b). SQGs that protected 95% of species were not derived, rather the SQGs were derived that protect 99, 80 and 60% of species. The SQGs that aim to protect 99% of species based on NOEC and EC10 data ranged from 1 to 20 mg/kg added Ni. The SQGs that aim to protect 80% of species based on NOEC and EC10 data ranged from 10 to 170mg/kg added Ni. These comparisons indicate that the SQGs derived in this project are slightly more conservative than the EC values, but overall the values are similar.

Table 82. Soil quality guidelines for nickel (Ni) in a number of international jurisdictions.

Name of the Ni soil quality guideline	Value of the guideline (mg/kg Ni)
Dutch target values[1]	35 (added Ni)
Dutch intervention value[1]	210 (added Ni)
Canadian SQG (residential, commercial and industrial)[2]	50 (total Ni)
Eco-SSL plants[3]	38 (total Ni)
Eco-SSL soil invertebrates[3]	280 (total Ni)
Eco-SSL avian[3]	210 (total Ni)
Eco-SSL mammalian[3]	130 (total Ni)
EU minimal risk values (residential)[4]	24 – 60 (added & total Ni)
EU warning risk values (residential)	30 – 180 (added & total Ni)
EU potential risk values (residential)[4]	30 – 500 (added & total Ni)
EC Ni ecological risk assessment (conc that should protect 95% of species)[5]	8.3 to 188.7 (added & total Ni)

1 = VROM 2000
2 = CCME 1999g, 2006 and <http://ceqg-rcqe.ccme.ca/>
3 = <http://www.epa.gov/ecotox/ecossl/>
4 = Carlon 2007
5 = EC 2008b.

10 Trivalent chromium

10.1 Chromium (III) compounds considered

Chromium occurs in a number of oxidation states: II, III, IV, V and VI. The two dominant states in soils are trivalent (III) and hexavalent (VI) Cr. Many of the publications which contained toxicity data for Cr (III) did not state the chemical which supplied the Cr (III). The only Cr (III) chemicals mentioned were chromium chloride, chromium nitrate and chromium sulphate.

10.2 Exposure pathway asssment

Chromium is the seventh most abundant element (McGrath 1990). It is also an essential element for humans and for some groups of organisms (Crommentuijn et al. 2000), yet the hexavalent form is generally considered to be highly toxic and a carcinogen.

The two key considerations in determining the most important exposure pathways for inorganic contaminants, such as Cr (III), are whether they biomagnify and whether they have the potential to leach to groundwater. A surrogate measure of the potential for a contaminant to leach is its water to soil partition coefficient (Kd). If the logarithm of the Kd (log Kd) of an inorganic contaminant is less than three then it is considered to have the potential to leach to groundwater (Schedule B5b). The log Kd reported by Commentuijn et al. (2000) for Cr (with the oxidation state not identified) was 2.04 L/kg; therefore, Cr has the potential in some soils to leach to groundwater. However, the ability of Cr to migrate from soil to either groundwater or surface water depends greatly on its oxidation state. Hexavalent Cr is highly water soluble whereas trivalent Cr is almost insoluble in water and immobile in soil (Bartlett & James 1988; Cervantes et al. 2001). Therefore, Cr (III) is unlikely to pose an environmental risk by leaching. In addition, Cr (III) cannot cross most cells (Cervantes et al. 2001). In contrast, Cr (VI) is actively transported across cell membranes (Dreyfuss, 1964; Wiegand et al. 1985). Chromium (III) is not known to biomagnify (Danish EPA;Scott-Fordsmand & Pedersen 1995; Heemsbergen et al. [2008]) and therefore only direct toxicity routes of exposure were considered in deriving the SQGs for Cr (III).

10.3 Toxicity data

Unlike the preceding elements, there is a lack of ecotoxicity data for Cr (III). This is reflected by the fact that the US EPA (US EPA 2008) could not derive Eco-SSL values (which require toxicity data for species belonging to three different types of organisms) for Cr (either as III or VI) for soil invertebrates and plants. Also neither the Canadians (CCME 1999h,) or the Dutch (Crommentuijn et al. 2000) have SQGs for Cr (III) but simply total Cr.

Extensive searches of the available scientific literature were conducted on ISI web of knowledge, the US EPA ECOTOX database (<http://cfpub.epa.gov/ecotox>), the Dutch RIVM e-toxbase database (<http://www.e-toxbase.com> – this is not publicly available), the database of the French National Institute of Industrial Environment and Risk (INERIS, <www.ineris.fr>), and the Australasian Ecotoxicology Database (Warne et al. 1998; Warne & Westbury 1999; Markich et al. 2002; Warne et al. in press). There were a number of publications (Bonet et al. 1991; Scoccianti et al. 2006) which presented toxicity data for Cr (III) which were not included in the derivation of SQGs in this guideline. This was because these were based on exposing plants solely via aqueous media (that is, hydroponics) or the growth media was agar and this is vastly different to exposure via soil.

The raw toxicity data for Cr (III) are presented in Appendix I. The toxicity data (geometric means for each species) used to calculate the SQGs are presented in Table 83. There were toxicity data for a total of 21 species or soil microbial processes. There were data for two soil invertebrate species, 12 species of plants and seven soil microbial processes. These data meet the minimum data requirements recommended in Schedule B5b to use the BurrliOZ SSD method (Campbell et al. 2000). The toxicity data for nitrogenase were not used as they were all less than values and the lowest concentration tested (that is, 50 mg/kg) caused an effect considerably larger than 50%. It should be noted that the toxicity data for the enzyme catalase were markedly lower (that is, more than one order of magnitude) than all the other toxicity data. Given this and the fact that the toxicity data were quantified using nominal (not measured) concentrations, there is uncertainty in the reliability of these data. Therefore the catalase toxicity data were not used to derive the SQGs.

Table 83. The lowest geometric mean values of normalised (invertebrate) and non-normalised (all other species and microbial processes) trivalent chromium (Cr (III)) toxicity data (expressed in terms of added Cr (III) for soil invertebrate species, plant species, and soil microbial processes.

Test species		Geometric mean (mg/kg)		
Common name	**Scientific name**	**EC10 or NOEC**	**EC30 or LOEC**	**EC50**
Arylsulfatase		121	181	321
Barley	*H. vulgare*	200	300	600
Beans		200	500	600
Bentgrass	*Agrostis tenius*	3333	5000	10000
Bush bean	*Phaseolus vulgaris*	41	70.7	141
Catalase		0.19	0.88	2.32
Corn	*Z. mays*	294	611	1233
Earthworm	*E. fetida*	467	700	1400
Earthworm	*E. Andrei*	25.4	79.5	159
Glutamic acid decomposition		55	400	800
Grass		200	500	600
Indian mustard	*Brassica juncea*	500	750	1100
Lettuce	*L. sativa*	500	387	775
Nitrogenase		<<50	<<50	<<50
Nitrogen mineralisation		172	302	626
Nitrogenate formation		50	200	500
Oat	*A. sativa*	339	508	1016
Perennial ryegrass	*L. perenne*	3333	5000	10000
Radish	*R. sativus*	500	387	775
Respiration		36.3	114	139
Rye	*Secale cereale*	233	350	700
Urease		71.2	122	205

In order to maximise the use of the available toxicity data, conversion factors provided in Schedule B5b were used to permit the inter-conversion of NOEC, LOEC, EC50, EC30 and EC10 data. The conversion factors used are presented in Table 17.

10.4 Normalisation relationships

There are only three published normalisation relationships for Cr (III) toxicity (Sivakumar & Subbhuraam 2005). They all relate the toxicity of Cr (III) to survival of *E. fetida* and are presented in Table 84. These are all based on clay content. The logarithmic form of normalisation relationship 1 was used to normalise the *E. fetida and E. andrei* toxicity data. This relationship was not applied to the toxicity data of the other species/microbial processes as they do not belong to the same organism type (that is, soft-bodied invertebrate) as the earthworm. This approach is consistent with the method recommended in Schedule B5b and adopted in the various EC ecological risk assessments that have been conducted for metals (EC 2008a; EC 2008b; LDA 2008).

Table 84. Normalisation relationships for the toxicity of trivalent chromium (Cr (III)) to soil invertebrates. The relationship used to normalise the toxicity data is in bold.

Eqtn no.	Species/soil process	Y parameter	X parameter(s)	Reference
1	*E. fetida*	log EC50	**-5.46 clay content + 1905.93** (r^2 = 0.92)	Sivakumar and Subbhuraam, 2005.
2			-5.75 clay content – 10.62 pH + 1980.46 (r^2 = 0.92)	
3			-3.59 clay content + 4.16 pH + 65.83 soil N + 1748.22 (r^2 = 0.95)	

10.5 Sensitivity of organisms to trivalent chromium

Figure 10 shows the SSD (that is, the cumulative distribution of the geometric means of species' sensitivities to Cr (III)) for all species for which Cr (III) toxicity data were available. Due to the limited amount of Cr (III) toxicity data and the fact that the data were not normalised (and thus soil properties affect the values), it is difficult to draw conclusions regarding the relative sensitivity of plants, invertebrates and soil processes to Cr (III). Given the lack of data and the overlaps in the sensitivity of the organsm types, all the Cr (III) toxicity data were used to derive the SQGs.

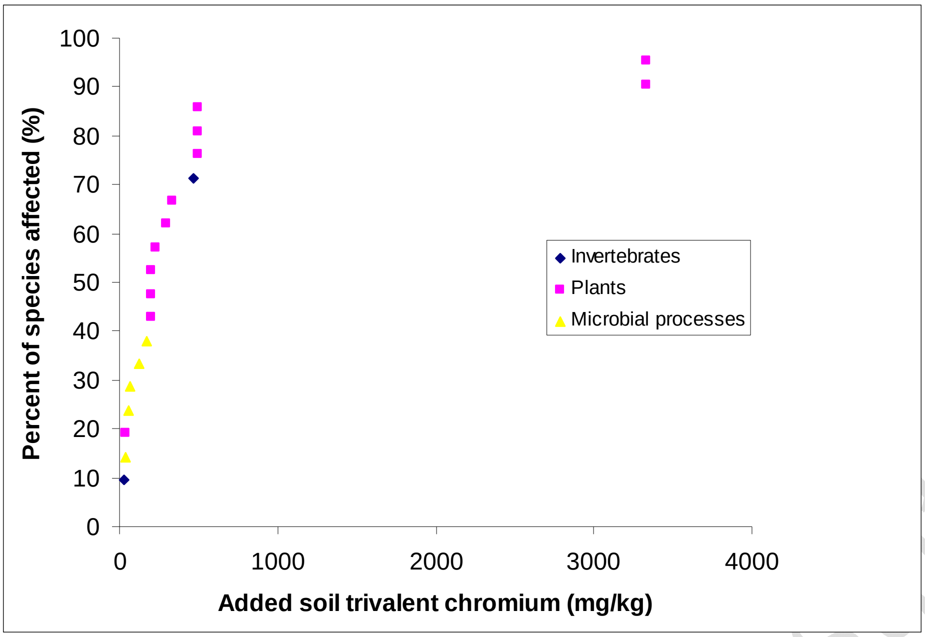


Figure 10. The SSD (plotted as a cumulative frequency against added trivalent chromium (Cr (III)) concentration) of Cr (III) for soil invertebrate species, plant species and soil microbial processes.

10.6 Calculation of soil quality guidelines for fresh trivalent chromium contamination

10.6.1 Calculation of added contaminant limits for fresh trivalent chromium contamination

Only the Cr (III) toxicity data for *E. fetida* and *E. andrei* could be normalised to the Australian reference soil. Thus, a set of generic (non-soil-specific) ACLs and a set of soil-specific ACLs were derived (for the earthworms). The soil-specific ACL values below a clay content of 10% were smaller than the generic ACL values. The soil-specific ACL at a clay content of 10% equalled the generic ACL, and all soil-specific ACLs for soils with a clay content greater than 10% were larger than the generic ACLs. The lower of the soil-specific ACL values and the generic ACL values were adopted as the final ACLs for Cr (III). Thus, the situation was simplified to the soil-specific ACLs only applying up to a clay content of 10% at which point the generic ACL values apply. The generated ACLs for the three land uses and the three types of toxicity data (that is, NOEC and EC10, LOEC and EC30, EC50) are presented in Table 85.

The range between the largest and smallest ACL values generated was approximately 4.0 to 470 mg added Cr (III)/kg. The residential/urban ACLs based on NOEC and EC10, LOEC and EC30, and EC50 data ranged from 35 to 75, 75to 160, and 110 to 230 mg added Cr (III)/kg respectively.

Table 85. The ACLs based on NOEC and 10% effect concentration (EC10) data, LOEC and 30% effect concentration (EC30), and 50% effect concentration (EC50) toxicity data for trivalent chromium (Cr (III)) for various land uses. These are based on all the Cr (III) toxicity data bar the catalase and nitrogenise enzyme activitity data.

Data type	Land use	Clay content			
		1	2.5	5	≥10
NOEC	NP	4	6	7	9
	UR	35	45	60	75
	C/I	65	90	110	140
LOEC	NP	25	30	40	50
	UR	75	100	130	160
	C/I	120	170	210	270
EC50	NP	9	10	15	20
	UR	110	150	190	230
	C/I	220	300	375	470

NP = national park/area with high ecological value
UR = urban residential/public open space
C/I = commercial/industrial land uses.

10.6.2 Calculation of ambient background concentration values for fresh trivalent chromium contamination

For sites with no history of Cr (III) contamination, the method of Hamon et al. (2004) is recommended to estimate the Cr ABC. Technically this method predicts total Cr but under aerobic soil conditions the vast majority of Cr will be present as Cr (III). It is therefore appropriate to use the Hamon et al (2004) method to estimate Cr (III) ABC values. The equation to predict the Cr ABC is:

$$\log \text{Cr conc (mg/kg)} = 0.75 \log \text{Fe content (\%)} + 1.242 \qquad \textit{(equation 12)}$$

Examples of the ABC values predicted by this equation are presented in Table 86. Predicted ABC values for Cr (III) range from approximately 3 to 170 mg/kg in soils with iron concentrations between 0.1 and 20%.

Table 86. ABCs for chromium (Cr) predicted using the method of Hamon et al. (2004) (equation 12 above).

Fe content (%)	Predicted Cu ABC (mg/kg)
0.1	3
0.5	10
1	15
2	30
5	60
10	100
15	130
20	160

10.6.3 Examples of soil quality guidelines for fresh trivalent chromium contamination in Australian soils

ABC values for Cr (III) vary with soil type (Table 86). Therefore, it is not possible to present a single set of SQG values. Thus, two examples of Cr (III) $SQG_{(NOEC \& EC10)}$ values, $SQG_{(LOEC \& EC30)}$ values and $SQG_{(EC50)}$ values are provided below. These examples would be at the low and high end of the range of SQG values (but not the extreme values) generated for Australian soils.

$SQG_{(NOEC \& EC10)}$ Example 1

Site descriptors - urban residential land/public open space use in a new suburb.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10, clay content 2.5%) with 1% iron content.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:
$ACL_{(NOEC \& EC10)}$: 45 mg/kg
ABC: 15 mg/kg
$SQG_{(NOEC \& EC10)}$: 60 mg/kg

$SQG_{(NOEC \& EC10)}$ Example 2

Site descriptors – commercial/industrial land use in a new suburb.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40, clay content 20%) with a 10% iron content.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:
$ACL_{(NOEC \& EC10)}$: 145 mg/kg
ABC: 100 mg/kg
$SQG_{(NOEC \& EC10)}$: 245 mg/kg which would be rounded off to 250 mg/kg.

$SQG_{(LOEC \& EC30)}$ Example 1

Site descriptors - urban residential land /public open space use in a new suburb.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10, clay content 2.5%) with 1% iron content.

The resulting $ACL_{(LOEC \& EC30)}$, ABC and $SQG_{(LOEC \& EC30)}$ values are:
$ACL_{(LOEC \& EC30)}$: 100 mg/kg
ABC: 15 mg/kg
$SQG_{(LOEC \& EC30)}$: 115 mg/kg which would be rounded off to 110 mg/kg.

$SQG_{(LOEC \& EC30)}$ Example 2

Site descriptors – commercial/industrial land use/public open space in a new suburb.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40, clay content 20%) with a 10% iron content.

The resulting $ACL_{(LOEC \& EC30)}$, ABC and $SQG_{(LOEC \& EC30)}$ values are:
$ACL_{(LOEC \& EC30)}$: 250 mg/kg
ABC: 100 mg/kg
$SQG_{(LOEC \& EC30)}$: 380 mg/kg

$SQG_{(EC50)}$ Example 1

Site descriptors - urban residential land/public open space use in a new suburb.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10, clay content 2.5%) with a 1% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:
$ACL_{(EC50)}$: 150 mg/kg
ABC: 15 mg/kg
$SQG_{(EC50)}$: 165 mg/kg which would be rounded off to 170 mg/kg

$SQG_{(EC50)}$ Example 2

Site descriptors – commercial/industrial land use in a new suburb.

Soil descriptors – an alkaline clay soil (clay content 20%) with a 10% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:
$ACL_{(EC50)}$: 470 mg/kg
ABC: 100 mg/kg
$SQG_{(EC50)}$: 570 mg/kg

10.7 Calculation of soil quality guidelines for aged trivalent chromium contamination

10.7.1 Calculation of an ageing and leaching factor for trivalent chromium

There are no ALFs available for Cr (III) nor data available to derive ALFs. Therefore, as an interim measure, the mean of the ALF values available for other cations (that is, Cd, Cu, Cobalt (Co), Ni, Pb and Zn) from Smolders et al. (2009) was determined. This resulted in a value of 2.35[4] which was rounded off to 2.5.

10.7.2 Calculation of added contaminant limits for aged trivalent chromium contamination

All the Cr (III) toxicity data were multiplied by the ALF of 2.5. Therefore, the aged SQG(NOEC & EC10), SQG(LOEC & EC30) and SQG(EC50) values are exactly 2.5 times the corresponding fresh SQGs for Cr (III). The resulting aged SQG(NOEC & EC10), SQG(LOEC & EC30) and SQG(EC50) values are presented in Table 87.

10.7.3 Calculation of ambient background concentration values

For aged contaminated sites (that is, the contamination has been in place for at least 2 years, Schedule B5b) the methodology recommends using the 25th percentiles of the ABC data for the 'old suburbs' of Olszowy et al. (1995) (see Table 88). Chromium concentrations in old suburbs are higher than those for new suburbs (Olszowy et al. 1995); therefore, it is appropriate to use the ABC values for aged suburbs. The Cr concentrations reported by Olszowy et al (1995) are for total Cr, however as was the case with the Hamon et al. (2004) method, the majority of the Cr measured will be Cr (III) and thus these data can be used to estimate ABC values for Cr (III). The Olszowy et al. (1995) data were derived from soils low in geogenic Cr and, through utilising low ABCs, could create low SQGs in some areas with naturally high background Cr concentrations. This problem could be overcome in areas of high natural Cr (III) by using measured ABC values or using the Hamon et al. (2004) method.

[4] For cations with a single ALF these were used to calculate the mean ALF. For cations with a range of values both the lowest and highest values were used to calculate the mean. Therefore the value of 2.35 was the mean of 3, 2, 1, 1, 3, 1.1, 3.5, 4.2, 1.

Table 87. The ACLs based on NOEC and 10% effect concentration (EC10) data, LOEC and 30% effect concentration (EC30), and 50% effect concentration (EC50) toxicity data for trivalent chromium (Cr (III)) for various land uses. These are based on all the Cr (III) toxicity data bar the catalase and nitrogenise enzyme activitity data.

Data type	Land use	Clay content			
		1	2.5	5	≥10
NOEC	NP	10	15	20	20
	UR	85	120	150	190
	C/I	170	230	280	360
LOEC	NP	60	80	100	130
	UR	190	250	310	400
	C/I	310	420	530	660
EC50	NP	25	30	40	50
	UR	275	370	460	580
	C/I	550	750	940	1200

NP = National park/area with high ecological value, UR = urban residential/public open space, C/I = commercial/industrial land uses.

Table 88. Chromium ABCs based on the 25 percentiles of Cr concentrations in 'old suburbs' (that is, > 2 years old) from various states of Australia (Olszowy et al. 1995).

Suburb type	25th percentile of Cr ABC values (mg/kg)			
	NSW	QLD	SA	VIC
Old suburb low traffic	8	15	15	10
Old suburb high traffic	15	7	15	10

10.7.4 Examples of soil quality guidelines for aged trivalent chromium contamination in Australian soils

ABC values for Cr (III) vary with soil type and location (Table 88). Therefore, it is not possible to present a single set of SQG values. Thus, two examples of Cr (III) $SQG_{(NOEC \& EC10)}$ values, $SQG_{(LOEC \& EC30)}$ values and $SQG_{(EC50)}$ values for aged Cr (III) contamination are provided below. These examples would be at the low and high end of the range of SQG values (but not the extreme values) generated for Australian soils.

$SQG_{(NOEC \& EC10)}$ Example 1

Site descriptors - urban residential land /public open space use in an old Victorian suburb with low traffic volume.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10, clay content 2.5%) with 1% iron content.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:
$ACL_{(NOEC \& EC10)}$: 120 mg/kg
ABC: 10 mg/kg
$SQG_{(NOEC \& EC10)}$: 130 mg/kg

$SQG_{(NOEC \& EC10)}$ Example 2

Site descriptors – commercial/industrial land use in an old NSW suburb with high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40, clay content 20%) with a 10% iron content.

The resulting $ACL_{(NOEC \& EC10)}$, ABC and $SQG_{(NOEC \& EC10)}$ values are:

$ACL_{(NOEC \& EC10)}$:	360 mg/kg
ABC:	15 mg/kg
$SQG_{(NOEC \& EC10)}$:	375 mg/kg which would be rounded off to 370 mg/kg

$SQG_{(LOEC \& EC30)}$ Example 1

Site descriptors - urban residential land /public open space use in an old Victorian suburb with low traffic volume.

Soil descriptors – a sandy acidic soil (pH 5, CEC 10, clay content 2.5%) with 1% iron content.

The resulting $ACL_{(LOEC \& EC30)}$, ABC and $SQG_{(LOEC \& EC30)}$ values are:

$ACL_{(LOEC \& EC30)}$:	250 mg/kg
ABC:	10 mg/kg
$SQG_{(LOEC \& EC30)}$:	260 mg/kg

$SQG_{(LOEC \& EC30)}$ Example 2

Site descriptors – commercial/industrial land use in an old NSW suburb with high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40, clay content 20%) with a 10% iron content.

The resulting $ACL_{(LOEC \& EC30)}$, ABC and $SQG_{(LOEC \& EC30)}$ values are:

$ACL_{(LOEC \& EC30)}$:	660 mg/kg
ABC:	15 mg/kg
$SQG_{(LOEC \& EC30)}$:	675 mg/kg which would be rounded off to 670 mg/kg

$SQG_{(EC50)}$ Example 1

Site descriptors - urban residential land /public open space use in an old Victorian suburb with low traffic volume. Soil descriptors – a sandy acidic soil (pH 5, CEC 10, clay content 2.5%) with 1% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$:	370 mg/kg
ABC:	10 mg/kg
$SQG_{(EC50)}$:	380 mg/kg

$SQG_{(EC50)}$ Example 2

Site descriptors – commercial/industrial land use in an old NSW suburb with high traffic volume.

Soil descriptors – an alkaline clay soil (pH 7.5, CEC 40, clay content 20%) with a 10% iron content.

The resulting $ACL_{(EC50)}$, ABC and $SQG_{(EC50)}$ values are:

$ACL_{(EC50)}$:	1200 mg/kg
ABC:	15 mg/kg
$SQG_{(EC50)}$:	1215 mg/kg which would be rounded off to 1200 mg/kg

10.8 Reliability of the soil quality guidelines

The Cr (III) toxicity data set met the minimum data requirements to use the SSD method but there was only one normalisation relationship available (for the earthworm *E. fetida*) to account for soil characteristics. Based on the criteria for assessing the reliability of SQGs in Schedule B5b, this means that the Cr (III) SQGs were considered to be of moderate reliability.

10.9 Comparison with other guidelines

A compilation of SQGs for Cr (III), Cr (VI) and total Cr from a number of international jurisdictions is presented in Table 89. These guidelines have a variety of purposes and levels of protection and therefore comparison of the values is problematic. The SQGs for Cr (III) range from 26 to 50 mg/kg (total Cr (III)). The majority of jurisdictions do not have SQGs for Cr (III), more typically they have SQGs for total Cr. Carlon (2007) in his review of the SQGs of members of the EU did not identify whether the SQGs were for added or total Cr, nonetheless they range from 34 to 1000 mg/kg. Hexavalent Cr is typically considered to be more toxic than Cr (III) and this is reflected by it having lower SQGs (Table 89).

The ACLs for fresh Cr (III) contamination that apply to urban residential land/public open space use based on NOEC and EC10, LOEC and EC30, and EC50 data ranged from 35 to 75, 75 to 160, and 100 to 230 mg added Cr (III)/kg respectively. The SQGs based on NOEC and EC10 data are closest to the existing international SQGs for Cr (III). It should be noted that all of the ACLs for urban residential land/public open space use (irrespective of which data was used to generate them) are considerably smaller than the superceded interim urban EIL of 400 mg total Cr/kg (NEPC 1999). However, the ACLs are consistent with the available Cr (III) toxicity data where there are six species/microbial processes that have EC50 values below the superceded interim urban EIL and there are 12 and 16 species/microbial processes that have LOEC and EC30 or NOEC and EC10 data respectively, below the superceded interim urban EIL. The species/microbial processes with toxicity values below the superceded interim urban EIL can be indentified by referring to Table 83.

The CLs for aged Cr (III) contamination that apply to urban residential land/public open space use based on NOEC and EC10, LOEC and EC30, and EC50 data ranged from 85 to 190, 175 to 400 and 270 to 580 mg added Cr (iII)/kg respectively. None of the ACLs based on NOEC & EC10 and LOEC & EC30 toxicity data were larger than the current interim EIL. However, once the clay content was 5% or above the ACL values based on EC50 data were larger than the superceded interim EIL. All of the ACLs for aged Cr (III) contamination are considerably larger than the collated international Cr (III) SQGs.

Table 89. Soil quality guidelines (mg/kg) for total chromium, trivalent chromium (Cr (III)) and hexavelent chromium (Cr (VI)) from international jurisdictions.

Name of chromium soil quality guideline	Total chromium	Trivalent chromium	Hexavalent chromium
Canadian SQG (residential)[1]			0.4 (total)
Canadian SQG (commercial and industrial)[1]			1.4 (total)
Danish soil quality guideline[2]		50 (total)	2 (total)
Dutch target value[3]	100 (added Cr)		
Dutch maximum permissible addition[3]	380 (added Cr)		
Eco-SSL plants[4]		ID	ID
Eco-SSL soil invertebrates[4]		ID	ID
Eco-SSL avian[4]		26 (total)	ID
Eco-SSL mammalian[4]		34 (total)	130 (total)
EU minimal risk values (residential)[5]	34 – 130 (added & total)		2.5 (added & total)
EU warning risk values (residential)[5]	50 – 450 (added & total)		4.2 – 20 (added & total)
EU potential risk values (residential)[5]	100 – 1000 (added & total)		

1 = CCME, 1999h and 2006 and http://ceqg-rcqe.ccme.ca/
2 = Scott-Fordsmand and Pedersen, 1995
3 = VROM, 2000
4 = http://www.epa.gov/ecotox/ecossl/
5 = Carlon, 2007; ID = insufficient data.

11 Summary

The methodology for deriving SQGs, detailed in Schedule B5b, was implemented to calculate SQGs based on different types of toxicity data for eight contaminants (that is, arsenic, chromium, copper, DDT, lead, naphthalene, nickel, zinc). These eight chemicals were selected as they have a variety of physicochemical properties and as a result they would behave differently in the environment and they are frequently found in urban Australian contaminated sites. The results of this process are summarised below for each contaminant. Some contaminants have the potential to leach from the contaminated site and thus may cause deleterious effects on groundwater and surface water ecosystems. The fact that contaminants can leach can be taken into account in deriving SQGs. This was done for zinc and arsenic, to illustrate the process and to illustrate the effect that it can have on the resulting SQG.

There was a considerable amount of toxicity data available for the essential element zinc. Zinc does not biomagnify but has the potential to leach from contaminated soil to groundwater. The minimum data requirements to use the SSD method were exceeded, there were multiple normalisation relationships, and there was an ageing/leaching factor. The toxicity data could be expressed in terms of added Zn concentrations; therefore, high reliability soil-specific Zn $ACL_{(NOEC\ \&\ EC10)}$, $ACL_{(LOEC\ \&\ EC30)}$ and $ACL_{(EC50)}$ values and corresponding SQG values could be derived for:

- fresh contamination
- aged contamination
- protection of aquatic ecosystems
- national park/area with high ecological value , urban residential/public open space, and commercial/industrial land uses.

Soil-specific ACLs could be derived, therefore a suite of values were generated. For example, the $ACL_{(NOEC\ \&\ EC10)}$ values for urban residential/public open space sites freshly contaminated with Zn ranged from 20 (at a cation exchange capacity of 5 and a soil pH of 4) to 330 mg/kg (at a cation exchange capacity of 60 and a soil pH of 7.5). The range of ACL values reflects the ability of different soils to modify the bioavailability and toxicity of Zn. Correcting for ageing led to a marked increase in the ACL values. The corresponding $ACL_{(NOEC\ \&\ EC10)}$ values for aged Zn contamination range from 45 to 800 mg/kg. As such, correcting for the ageing of Zn led to more than doubling of the recommended ACL values. The $ACL_{(LOEC\ \&\ EC30)}$ and $ACL_{(EC50)}$ values were approximately 1.25 and 1.5 and 2 times larger, respectively, than the corresponding $ACL_{(NOEC\ \&\ EC10)}$ values. The lowest of the Zn ACLs for urban residential land/public open space (that is, 20 mg/kg) are essentially identical to the lowest corresponding international SQGs, while the higher Zn ACLs are considerably larger than any international SQG.

Arsenic does not biomagnify in oxidised soils but has the potential to leach from contaminated soil to groundwater. Therefore, only the direct toxicity route of exposure needs to be considered in deriving the SQGs. The minimum data requirements to use the SSD method were exceeded, there were no normalisation relationships, and an ageing/leaching factor was available.

The toxicity data could only be expressed in terms of total As concentrations, therefore moderate reliability generic (not soil-specific) As $SQG_{(NOEC\ \&\ EC10)}$, $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ could be derived for:

- fresh contamination
- aged contamination
- protection of aquatic ecosystems
- national park/area with high ecological value, urban residential/public open space, and commercial/industrial land uses.

The generic As $SQG_{(NOEC\ \&\ EC10)}$ value for soils with national park/area with high ecological value, urban residential/public open space and commercial/industrial land uses were 8, 20 and 30 mg/kg (total As) respectively. The $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values were approximately 2.5 and 3.75 to 5 times larger, respectively, than the corresponding $SQG_{(NOEC\ \&\ EC10)}$ values. The As $SQG_{(NOEC\ \&\ EC10)}$ for urban residential/public open space soils is identical to the superceded interim urban EIL of 20 mg/kg (NEPC1999a). Both the As $SQG_{(NOEC\ \&\ EC10)}$ and the superceded EIL lie in the lower portion of the range of international As SQGs. The $SQG_{(NOEC\ \&\ EC10)}$ for aged contamination at 40 mg/kg was twice the superceded interim urban EIL for As. The aged As $SQG_{(LOEC\ \&\ EC30)}$ for urban residential/public open space soils lies in the upper part of the range of international SQGs while the aged As $SQG_{(EC50)}$ value for urban residential/public open space soils is markedly larger than any other international SQG.

Naphthalene does not biomagnify and has only a moderate potential to leach to groundwater. Therefore, only the direct toxicity exposure route was considered in deriving the SQGs. The minimum data requirements to use the SSD method were exceeded, there were no normalisation relationships, and there was no ageing/leaching factor. The toxicity data could only be expressed as total naphthalene concentrations. Therefore, moderate reliability generic (not soil-specific) naphthalene $SQG_{(NOEC\ \&\ EC10)}$, $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values could be derived for:

- fresh contamination
- national park/area with high ecological value , urban residential/public open space and commercial/industrial land uses.

The generic naphthalene $SQG_{(NOEC\ \&\ EC10)}$ values for soils with national park/areas with high ecological value, urban residential/public open space and commercial/industrial land uses were 5, 70 and 150 mg/kg (total naphthalene) respectively. The $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values were approximately 2 to 2.5 and 5 times larger, respectively, than the corresponding $SQG_{(NOEC\ \&\ EC10)}$ values. There are only a very limited number of international SQGs for naphthalene which differ markedly (that is, 0.6 to 125). The $SQG_{(NOEC\ \&\ EC10)}$ for urban residential/public open space soils of 70 mg/kg is very similar to the top of the EU range of SQGs and in the middle of the range of collated international SQGs.

DDT biomagnifies and has a very low potential to leach to groundwater. Therefore, only the biomagnification and direct toxicity exposure pathways were assessed in deriving SQGs. The minimum data requirements to use the SSD method were exceeded, there were no normalisation relationships, and there was no ageing/leaching factor. The toxicity data could only be expressed as total DDT concentrations. Therefore, moderate reliability generic (not soil-specific) DDT $SQG_{(NOEC\ \&\ EC10)}$, $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ could be derived for:

- fresh contamination
- national park/area with high ecological value , urban residential/public open space, and commercial/industrial land uses.

The generic DDT $SQG_{(NOEC\ \&\ EC10)}$ values for soils with national park/area with high ecological value, urban residential/public open space and commercial/industrial land uses were 1, 70 and 250 mg/kg (total DDT) respectively. The $SQG_{(LOEC\ \&\ EC30)}$ and $SQG_{(EC50)}$ values were approximately 2.6 to 2 and 5 to 6 times larger, respectively, than the corresponding $SQG_{(NOEC\ \&\ EC10)}$ values. The international SQGs for DDT range from 0.01 to 4 mg/kg. The $SQG_{(NOEC\ \&\ EC10)}$ value for freshly contaminated urban residential/public open space soil is thus considerably larger than the international guidelines but is considerably smaller than the HILs which range from 260 to 4000 mg/kg (see Schedule B1).

Copper is an essential element. It has a low potential to leach to groundwater. Copper does not biomagnify and therefore only direct toxic effects were considered. There was an extensive toxicity data set for Cu (39 species or soil microbial processes). There were normalisation relationships available for plants, invertebrates and soil microbial processes. An ageing/leaching factor was also available. Therefore high reliability soil-specific ACLs could be derived using NOEC and EC10, LOEC and EC30, and EC50 data for:

- fresh contamination
- aged contamination
- national park/area with high ecological value, urban residential/public open space, and commercial/industrial land uses.

The $ACL_{(NOEC\ and\ EC10)}$ values for urban residential/public open space sites freshly contaminated with Cu ranged from approximately 20 (at a soil pH of 4.5) to 70 mg added Cu/kg (at a soil pH of 8). Correcting for ageing led to a marked increase in the ACL values. The corresponding ACL values for aged Cu contamination range from 30 to 120 mg added Cu/kg. The range of ACL values reflects the ability of different soils to modify the bioavailability and toxicity of Cu. The ACLs based on LOEC and EC30 data and based on EC50 data were approximately 1.5 to 2 and 2.5 to 3 times larger, respectively, than the corresponding SQGs based on NOEC and EC10 data. All of the Cu ACLs for residential land use lie within the range of international SQGs for Cu (that is, 14 to 1000 mg/kg). The superceded interim urban EIL for Cu was 100 mg/kg (total Cu). Therefore the superceded interim EIL for Cu falls within the range of values of all of the SQGs for urban residential land/public open space uses. The SQGs will permit both considerably less and considerably more Cu in urban residential/public open space soils depending on the properties of the soils.

Lead is not an essential element but it does not biomagnify in terrestrial ecosystems, nor does it have any significant potential to leach to groundwater. There were toxicity data for 19 species and soil microbial processes which included plants, invertebrates and soil microbial processes. There were no useful normalisation relationships. An ageing leaching factor has been published in the literature. Therefore moderate reliability generic (not soil-specific) Pb SQGs could be derived using NOEC and EC10, LOEC and EC30, and EC50 data for:

- fresh contamination
- aged contamination
- national park/area with high ecological value, urban residential/public open space, and commercial/industrial land uses.

The generic Pb ACLs for urban residential/public open space land use that were calculated using NOEC and EC10 data was 130 mg added Pb/kg. The equivalent SQG for aged Pb contamination was 530 mg added Pb/kg. The corresponding ACLs calculated using LOEC and EC30 and using EC50 data were approximately two and four times larger than the NOEC and EC10 derived ACL values. All the Pb ACLs for urban residential/public open space soils fell within the range of SQGs that have been adopted in other international jurisdictions (that is, 25 to 700 mg/kg).

The superceded interim urban EIL was 600 mg/kg (total Pb). All of the Pb SQGs for fresh contamination are lower than the superceded interim urban EIL. The aged SQGs based on NOEC and EC10 are slightly smaller than the superceded interim urban EIL while the SQGs based on LOEC and EC30 and based on EC50 data are considerably higher.

Nickel does not biomagnify therefore, only the direct toxicity exposure route was considered in deriving the SQGs. Nickel, however, does have the potential to leach to groundwater. There was toxicity data for a total of 53 plant and animal species or soil microbial processes. In addition, there were normalisation relationships available for invertebrates, plants and soil microbial processes. A soil pH modified ageing leaching factor was available. The minimum data requirements to use the SSD method were exceeded, there were no normalisation relationships, and there was no ageing/leaching factor. Therefore high reliability soil-specific ACLs could be derived using NOEC and EC10, LOEC and EC30, and EC50 data for:

- fresh contamination
- aged contamination
- national park/area with high ecological value, urban residential/public open space, and commercial/industrial, land uses.

The soil-specific Ni ACLs based on NOEC and EC10 data for urban residential/public open space soils ranged from 10 to 170 mg added Ni/kg for soils with a CEC ranging from 5 to 60 $cmol_c$/kg. The corresponding ACL values for aged Ni contamination ranged from 15 to 290 mg added Ni/kg. The ACL values based on LOEC and EC30 data and based on EC50 data were essentially identical and approximately three times larger than the NOEC and EC10 based ACL values. The range of international SQGs for Ni is 24 to 500 mg/kg. Thus, only the urban residential/public open space ACLs for soils with a CEC above 40 $cmol_c$/kg lie outside the range of internationally adopted SQGs. The superceded interim urban EIL for Ni was 60 mg/kg (total Ni). All of the SQGs would permit both lower and higher concentrations than the superceded interim urban EIL. In soils with a low Ni bioavailability the maximum recommended concentration of Ni that can be added is 15 times the superceded interim urban EIL.

Trivalent chromium is an essential element for humans and animals but not for plants. It does not pose a potential environmental problem due to leaching (unless it is oxidised to hexavalent chromium), nor does it biomagnify. Toxicity data were available for a total of 21 invertebrate and plant species and soil microbial processes. There were only normalisation relationships available for earthworms. There was no ageing leaching factor available for Cr (III). Therefore moderate reliability soil-specific ACLs could be derived using NOEC and EC10, LOEC and EC30, and EC50 data for:

- fresh contamination
- national park/area with high ecological value, urban residential/public open space and commercial/industrial land uses.

The soil-specific Cr (III) ACL values based on NOEC and EC10 data for urban residential / public open space land uses ranged from 35 to 75 mg added Cr (III)/kg for soils with a clay content from 1 to greater than 10%. The ACL values based on LOEC and EC30 and based on EC50 data were approximately 2 and 3 times larger than the NOEC-based ACLs. The ACLs for aged Cr (III) contamination were approximately 2.5 times larger than the corresponding ACLs for fresh contamination. The ACLs for Cr (III) based on NOEC and EC10 data are consistent with other internationally adopted Cr (III) SQGs. The ACL values based on LOEC and EC30 and on EC50 data are larger than the current international Cr (III) SQGs.

The superceded interim urban EIL for total Cr was 400 mg/kg. This is considerably higher than any of the SQGs for fresh Cr (III) by a factor of at least 2.6. The aged ACLs are essentially 2.5 times larger than the corresponding fresh ACLs.

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13 Appendices

13.1 Appendix A: Raw toxicity data for zinc

There are three tables in this appendix (Tables A1 to A3).

Table A1. Raw toxicity data for zinc to soil microbial processes with the corresponding toxicity values when they were normalised to the Australian reference soil, the corresponding values when corrected for ageing and leaching and the source of the data.

Geographical location	Soil process	Soil pH	Delta pH	EC10 or NOEC	Log EC10 or NOEC	Log normalised EC10 or NOEC	Normalised EC10 or NOEC	Age corrected normalised EC10 or NOEC	Source
Europe	Acetate decomposition	7.4	-1.4	303	2.48	2.27	187	560	Van Beelen et al. 1994
Europe	Amidase	7.4	-1.4	200	2.3	2.09	123	370	Hemida et al. 1997
Europe	Amidase	7.5	-1.5	200	2.3	2.08	119	357	Hemida et al. 1997
Europe	Ammonification	7.1	-1.1	1000	3	2.84	684	2052	Premi and Cornfield 1969
Europe	Arylsulphatase	6.2	-0.2	820	2.91	2.88	765	2296	Al-Khafaji and Tabatabai 1979
Europe	Arylsulphatase	7.8	-1.8	140	2.15	1.88	75	226	Al-Khafaji and Tabatabai 1979
Europe	Arylsulphatase	5.8	0.2	164	2.21	2.24	176	527	Al-Khafaji and Tabatabai 1979
Europe	Arylsulphatase	7.4	-1.4	820	2.91	2.7	506	1517	Al-Khafaji and Tabatabai 1979
Europe	Arylsulphatase	5.1	0.9	728	2.86	3	993	2980	Haanstra and Doelman 1991
Europe	Arylsulphatase	7.7	-1.7	105	2.02	1.77	58.4	175	Haanstra and Doelman 1991
Europe	Arylsulphatase	6.8	-0.8	2353	3.37	3.25	1785	5355	Haanstra and Doelman 1991
Europe	Arylsulphatase	7.4	-1.4	151	2.18	1.97	93	279	Haanstra and Doelman 1991
Europe	Denitrification	6.8	-0.8	100	2	1.88	76	228	Bollag and Barabasz 1979
Europe	Nitrate reductase	7.4	-1.4	67	1.83	1.62	41	124	Hemida et al. 1997
Europe	N-mineralization	6.9	-0.9	100	2	1.87	73	220	Chang and Broadbent 1982
Europe	N-mineralization	5.8	0.2	164	2.21	2.24	176	527	Liang and Tabatabai 1977
Europe	N-mineralization	6.6	-0.6	164	2.21	2.12	133	400	Liang and Tabatabai 1977
Europe	N-mineralization	7.8	-1.8	164	2.21	1.94	88	264	Liang and Tabatabai 1977
Europe	N-mineralization	7.4	-1.4	164	2.21	2	101	303	Liang and Tabatabai 1980
Europe	N-mineralization	3.4	2.6	233	2.37	2.76	572	1716	Necker and Kunze 1986
Europe	Phosphatase	5.1	0.9	1341	3.13	3.26	1830	5490	Doelman and Haanstra 1989
Europe	Phosphatase	6.8	-0.8	160	2.2	2.08	121	364	Doelman and Haanstra 1989
Europe	Phosphatase	7.4	-1.4	2623	3.42	3.21	1617	4852	Doelman and Haanstra 1989

Geographical location	Soil process	Soil pH	Delta pH	EC10 or NOEC	Log EC10 or NOEC	Log normalised EC10 or NOEC	Normalised EC10 or NOEC	Age corrected normalised EC10 or NOEC	Source
Europe	Phosphatase	5.8	0.2	164	2.21	2.24	176	527	Juma and Tabatabai 1977
Europe	Phosphatase	7.4	-1.4	164	2.21	2	101	303	Juma and Tabatabai 1977
Europe	Phosphatase	4.7	1.3	508	2.71	2.9	796	2388	Svenson 1986
Europe	Phytase	4.7	1.3	590	2.77	2.97	924	2773	Svenson 1986
Europe	Py-phosphatase	4.6	1.4	1640	3.21	3.42	2660	7979	Stott et al. 1985
Europe	Py-phosphatase	6.2	-0.2	1640	3.21	3.18	1531	4592	Stott et al. 1985
Europe	Py-phosphatase	7.4	-1.4	1640	3.21	3	1011	3034	Stott et al. 1985
Europe	Respiration	6.9	-0.9	17	1.23	1.1	12	37	Chang and Broadbent 1981
Europe	Respiration	6.7	-0.7	110	2.04	1.94	86	259	Lighthart et al. 1983
Europe	Respiration	7	-1	165	2.22	2.07	117	350	Lighthart et al. 1983
Europe	Respiration	7.2	-1.2	110	2.04	1.86	73	218	Lighthart et al. 1983
Europe	Respiration	8.2	-2.2	17	1.23	0.9	8	24	Lighthart et al. 1983
Europe	Respiration	5.2	0.8	50	1.7	1.82	66	198	Saviozzi et al., 1997
Europe	Respiration	3	3	120	2.08	2.53	338	1015	Smolders et al, 2003
Europe	Respiration	4.8	1.2	469	2.67	2.85	710	2130	Smolders et al, 2003
Europe	Respiration	5.1	0.9	50	1.7	1.83	68	205	Smolders et al. 2003
Europe	Respiration	5.7	0.3	1400	3.15	3.19	1553	4659	Smolders et al. 2003
Europe	Respiration	6.8	-0.8	38	1.58	1.46	29	86	Smolders et al. 2003
Europe	Respiration	7.4	-1.4	150	2.18	1.97	92	277	Smolders et al. 2003
Europe	Respiration	7.4	-1.4	600	2.78	2.57	370	1110	Smolders et al. 2003
Europe	Respiration	7.5	-1.5	150	2.18	1.95	89	268	Smolders et al. 2003
Europe	Respiration	7.5	-1.5	300	2.48	2.25	179	536	Smolders et al. 2003
Australia	SIN[1]	5.42	0.58	209	2.32	2.52	328	328	NBRP unpublished data[2]
Australia	SIN	4.52	1.48	63	1.8	2.3	200	200	NBRP unpublished data
Australia	SIN	7.26	-1.26	1181	3.07	2.64	440	440	NBRP unpublished data
Australia	SIN	4.89	1.12	346	2.54	2.92	829	829	NBRP unpublished data
Australia	SIN	3.96	2.04	10	1.01	1.7	50	50	NBRP unpublished data
Australia	SIN	4.39	1.61	70	1.84	2.39	247	247	NBRP unpublished data
Australia	SIN	5.03	0.97	270	2.43	2.76	577	577	NBRP unpublished data
Australia	SIN	5.13	0.87	901	2.95	3.25	1782	1782	NBRP unpublished data
Australia	SIN	6.32	-0.32	919	2.96	2.85	716	716	NBRP unpublished data

Geographical location	Soil process	Soil pH	Delta pH	EC10 or NOEC	Log EC10 or NOEC	Log normalised EC10 or NOEC	Normalised EC10 or NOEC	Age corrected normalised EC10 or NOEC	Source
Australia	SIN	6.33	-0.33	462	2.66	2.55	357	356	NBRP unpublished data
Australia	SIN	4.8	1.2	188	2.27	2.68	482	482	NBRP unpublished data
Australia	SIN	7.63	-1.63	7538	3.88	3.32	2110	2110	NBRP unpublished data
Australia	SIR[3]	5.42	0.58	158	2.2	2.4	249	249	NBRP unpublished data
Australia	SIR	4.52	1.48	369	2.57	3.07	1176	1176	NBRP unpublished data
Australia	SIR	7.26	-1.26	187	2.27	1.84	70	70	NBRP unpublished data
Australia	SIR	4.89	1.12	462	2.66	3.04	1105	1105	NBRP unpublished data
Australia	SIR	4.39	1.61	73	1.86	2.41	257	257	NBRP unpublished data
Australia	SIR	5.03	0.97	499	2.7	3.03	1064	1064	NBRP unpublished data
Australia	SIR	5.13	0.87	281	2.45	2.74	555	555	NBRP unpublished data
Australia	SIR	6.32	-0.32	25	1.41	1.3	20	20	NBRP unpublished data
Australia	SIR	6.33	-0.33	268	2.43	2.32	207	207	NBRP unpublished data
Australia	SIR	4.8	1.2	345	2.54	2.95	885	885	NBRP unpublished data
Australia	SIR	7.63	-1.63	190	2.28	1.73	53	53	NBRP unpublished data
Europe	Urease	5.1	0.9	30	1.48	1.61	41	123	Doelman and Haanstra 1986
Europe	Urease	7.7	-1.7	70	1.85	1.59	39	117	Doelman and Haanstra 1986
Europe	Urease	6.8	-0.8	460	2.66	2.54	349	1047	Doelman and Haanstra 1986
Europe	Urease	7.4	-1.4	30	1.48	1.27	19	55	Doelman and Haanstra 1986
Europe	Urease	7.4	-1.4	64	1.81	1.6	39	118	Tabatabai 1977
Europe	Urease	7.8	-1.8	52	1.72	1.45	28	84	Tabatabai 1977
Europe	Urease	5.8	0.2	109	2.04	2.07	117	350	Tabatabai 1977

1 SIN = substrate induced nitrification
2 = These EC10 data have not been published but were determined using the same biological response and soil concentration data as the EC50 values published in Broos et al. (2007)
3 SIR = substrate induced respiration.

Table A2. Raw toxicity data for zinc to soil invertebrates with the corresponding toxicity values when they were normalised to the Australian reference soil, the corresponding values when corrected for ageing and leaching and the source of the data.

Scientific name	Toxicity endpoint	CEC[1]	Log CEC	Delta log CEC	EC10 or NOEC	Log EC10 or NOEC	Log normalised EC10	Normalised EC10	Aged normalised EC10	Source
Acrobeloides sp.		3.6	0.56	0.44	99	1.99	2.34	221	663	Korthals et al. 1996
A. rosea[2]	survival	15	1.18	-0.18	538	2.73	2.59	391	1172	Spurgeon and Hopkin 1996
A. caliginosa	reproduction	9.2	0.97	0.03	210	2.32	2.35	223	669	Spurgeon et al. 2000
C. elegans[3]		2.4	0.38	0.62	112	2.05	2.54	345	1035	Boyd and Williams 2003
C. elegans		7.2	0.86	0.14	118	2.07	2.18	153	458	Boyd and Williams 2003
C. elegans		28.4	1.45	-0.45	383	2.58	2.22	168	504	Boyd and Williams 2003
C. elegans		10.0	1	0	25	1.4	1.4	25	76	Jonkers et al. 2004
C. elegans[4]		3.6	0.56	0.44	308	2.49	2.84	689	2068	Korthals et al. 1996
E. andrei[5]	reproduction	26	1.41	-0.41	320	2.51	2.18	152	456	van Gestel et al. 1993
E. fetida[5]	reproduction	26	1.41	-0.41	350	2.54	2.22	166	499	Spurgeon et al 1997
E. fetida	reproduction	26	1.41	-0.41	350	2.54	2.22	166	499	Spurgeon et al 1997
E. fetida	reproduction	15	1.18	-0.18	237	2.37	2.24	172	516	Spurgeon and Hopkin1996
E. fetida	reproduction	15	1.18	-0.18	199	2.3	2.16	144	433	Spurgeon et al 1994
E. fetida	reproduction	26	1.41	-0.41	553	2.74	2.42	263	788	Spurgeon and Hopkin1996
E. fetida	reproduction	18	1.27	-0.27	97	1.99	1.78	60	179	Spurgeon and Hopkin1996
E. fetida	reproduction	33	1.52	-0.52	484	2.68	2.28	189	568	Spurgeon and Hopkin1996
E. fetida	reproduction	16	1.21	-0.21	85	1.93	1.77	58	175	Spurgeon and Hopkin1996
E. fetida	reproduction	22	1.34	-0.34	183	2.26	2	99	297	Spurgeon and Hopkin1996
E. fetida	reproduction	27	1.44	-0.44	414	2.62	2.27	186	559	Spurgeon and Hopkin1996
E. fetida	reproduction	14	1.14	-0.14	115	2.06	1.95	90	269	Spurgeon and Hopkin1996
E. fetida	reproduction	18	1.25	-0.25	161	2.21	2.01	101	304	Spurgeon and Hopkin1996
E. fetida	reproduction	22	1.35	-0.35	223	2.35	2.08	119	357	Spurgeon and Hopkin1996
E. fetida	reproduction	5.8	0.76	0.24	180	2.26	2.44	277	830	Smolders et al. 2003
E. fetida	reproduction	1.9	0.28	0.72	100	2	2.57	371	1114	Smolders et al. 2003
E. fetida	reproduction	13.3	1.12	-0.12	320	2.51	2.41	255	766	Smolders et al. 2003
E. fetida	reproduction	11.2	1.05	-0.05	560	2.75	2.71	512	1536	Smolders et al. 2003

Scientific name	Toxicity endpoint	CEC	Log CEC	Delta log CEC	EC10 or NOEC	Log EC10 or NOEC	Log normalised EC10	Normalised EC10	Aged normalised EC10	Source
E. fetida	reproduction	4.7	0.67	0.33	320	2.51	2.76	581	1743	Smolders et al. 2003
E. fetida	reproduction	21.1	1.32	-0.32	1000	3	2.74	554	1663	Smolders et al. 2003
E. fetida	reproduction	23.4	1.37	-0.37	560	2.75	2.46	286	858	Smolders et al. 2003
E. fetida	reproduction	8.9	0.95	0.05	180	2.26	2.3	197	592	Smolders et al. 2003
E. fetida	reproduction	20.1	1.3	-0.3	180	2.26	2.02	104	311	Smolders et al. 2003
E. fetida	reproduction	16.9	1.23	-0.23	350	2.54	2.36	231	694	Smolders et al. 2003
E. fetida	reproduction	15	1.18	-0.18	572	2.76	2.62	415	1246	Spurgeon and Hopkin 1996
E. fetida	reproduction	9.2	0.97	0.03	792	2.9	2.93	843	2530	Spurgeon et al. 2000
E. albidus[6]		15	1.18	-0.18	262	2.42	2.28	190	571	Lock and Janssen 2001
E. albidus		15	1.18	-0.18	132	2.12	1.98	96	287	Lock and Janssen 2001
E. albidus		15	1.18	-0.18	180	2.26	2.12	131	392	Lock and Janssen 2001
E. albidus		11.5	1.06	-0.06	100	2	1.95	90	269	Lock and Janssen 2001
E. crypticus[6]		15	1.18	-0.18	380	2.58	2.44	276	828	Lock and Janssen 2001
Eucephalobus sp.		3.6	0.56	0.44	60	1.78	2.13	134	403	Korthals et al. 1996
F. candida[7]	reproduction	26	1.41	-0.41	366	2.56	2.1	125	375	Smit and van Gestel 1998
F. candida	reproduction	26	1.41	-0.41	620	2.79	2.33	212	636	Sandifer and Hopkin 1996
F. candida	reproduction	26	1.41	-0.41	399	2.6	2.13	136	409	Van Gestel & Henbergen 1997
F. candida	reproduction	5	0.66	0.34	275	2.44	2.83	680	2040	Smit and van Gestel 1998
F. candida	reproduction	5	0.66	0.34	314	2.5	2.89	776	2329	Smit and van Gestel 1998
F. candida	reproduction	22	1.34	-0.34	300	2.48	2.09	123	370	Sandifer and Hopkin 1996
F. candida	reproduction	20	1.3	-0.3	300	2.48	2.14	137	411	Sandifer and Hopkin 1996
F. candida	reproduction	26	1.41	-0.41	300	2.48	2.01	103	308	Sandifer and Hopkin 1997
F. candida	reproduction	1.9	0.28	0.72	32	1.51	2.33	213	638	Smolders et al. 2003
F. candida	reproduction	13.3	1.12	-0.12	320	2.51	2.36	231	694	Smolders et al. 2003
F. candida	reproduction	11.2	1.05	-0.05	100	2	1.94	88	264	Smolders et al, 2003
F. candida	reproduction	22.6	1.35	-0.35	320	2.51	2.1	126	379	Smolders et al. 2003
F. candida	reproduction	21.1	1.32	-0.32	320	2.51	2.14	137	410	Smolders et al. 2003
F. candida	reproduction	20	1.3	-0.3	560	2.75	2.41	254	762	Smolders et al. 2003
F. candida	reproduction	36.3	1.56	-0.56	1000	3	2.36	230	690	Smolders et al, 2003
F. candida	reproduction	16.9	1.23	-0.23	320	2.51	2.25	176	528	Smolders et al, 2003

Scientific name	Toxicity endpoint	CEC	Log CEC	Delta log CEC	EC10 or NOEC	Log EC10 or NOEC	Log normalised EC10	Normalised EC10	Aged normalised EC10	Source
L. rubellus[8]	reproduction	15	1.18	-0.18	121	2.08	1.94	88	264	Spurgeon and Hopkin 1996
L. rubellus	reproduction	9.2	0.97	0.03	517	2.71	2.74	550	1649	Spurgeon et al. 2000
L. rubellus	reproduction	9.2	0.97	0.03	325	2.51	2.54	346	1039	Spurgeon and Hopkin 1999
L. rubellus	reproduction	9.2	0.97	0.03	648	2.81	2.84	690	2069	Spurgeon and Hopkin 1999
L. rubellus	reproduction	9.2	0.97	0.03	470	2.67	2.7	500	1501	Spurgeon and Hopkin 1999
L. terrestris[8]	reproduction	9.2	0.97	0.03	998	3	3.03	1062	3187	Spurgeon et al. 2000
Nematode community		5.1	0.7	0.3	560	2.75	2.98	961	2882	Smit et al. 2002
Nematode community		5.1	0.7	0.3	180	2.26	2.49	309	926	Smit et al. 2002
Nematode community		5.1	0.7	0.3	180	2.26	2.49	309	926	Smit et al. 2002
Nematode community		5.1	0.7	0.3	56	1.75	1.98	96	288	Smit et al. 2002
Plectus sp.		3.6	0.56	0.44	10	1.02	1.37	23	70	Korthals et al. 1996
Rhabditidae sp.		3.6	0.56	0.44	89	1.95	2.3	199	597	Korthals et al. 1996

[1] CEC = cation exchange capacity
[2] A. = *Aporrectodea*
[3] C. = *Caenorhabditis*
[4]. dauer larval stage
[5] E. = *Eisenia*
[6] E. = *Enchytraeus*
[7] F. = *Folsomia*
[8] L. = *Lumbriculus.*

Table A3. Raw toxicity data for zinc to plant species with the corresponding toxicity values when they were normalised to the Australian reference soil, the corresponding values when corrected for ageing and leaching and the source of the data. The wheat toxicity was sourced from Warne et al. (2008a), all other Australian data are unpublished data from the Australian National Biosolids Research Program.

Site	Plant species	Scientific name	CEC	Log CEC	Delta CEC	pH	Delta pH	EC10	Log EC10	Log normalised EC10	Normalised EC10	Aged normalised EC10
Europe[1]	Alfalfa	*Medicago sativa*				7.50	-1.50	300.00	2.48	2.30	198.21	594.62
Australia	Barley	*Hordeum vulgare*	9.95	1.00	0.00	7.63	-1.63	56.36	1.75	1.31	20.49	20.49
Australia	Barley	*H. vulgare*	17.71	1.25	-0.25	6.32	-0.32	490.45	2.69	2.43	268.91	268.91
Australia	Barley	*H. vulgare*	10.29	1.01	-0.01	6.33	-0.33	486.69	2.69	2.59	387.88	387.88
Europe[1]	Barley	*H. vulgare*				7.50	-1.50	100.00	2.00	1.82		
Europe[2]	Barley	*H. vulgare*	17.64	1.25	-0.25	5.60	0.40	33.30	1.52	1.35	22.44	67.31
Europe[3]	Barley	*H. vulgare*				7.80	-1.80	215.00	2.33	2.12		
Europe[1]	Beet	*Beta vulgaris*				7.50	-1.50	300.00	2.48	2.30	198.21	594.62
Europe[4]	Black or white lentil	*Vigna mungo L.*				6.20	-0.20	100.00	2.00	1.98	94.62	283.87
Australia	Canola	*Brassica napus*	10.29	1.01	-0.01	6.33	-0.33	178.84	2.25	2.15	142.53	142.53
Australia	Canola	*B. napus*	3.16	0.50	0.50	5.42	0.58	139.13	2.14	2.65	448.08	448.08
Australia	Canola	*B. napus*	4.95	0.69	0.31	4.80	1.20	52.26	1.72	2.26	181.45	181.45
Australia	Canola	*B. napus*	12.99	1.11	-0.11	4.89	1.12	144.60	2.16	2.38	241.34	241.34
Europe[5]	Common vetch	*Vicia sativa*	12.46	1.10		5.00	1.00	32.00	1.51	1.63	42.18	126.55
Australia	Cotton	*Gossypium sp*	60.97	1.79	-0.79	7.26	-1.26	2127.60	3.33	2.44	272.44	272.44
Europe[6]	Fenugreek	*Trigonella foenum graceum*	17.02	1.23		8.30	-2.30	200.00	2.30	2.03	105.93	317.80
Europe[1]	Lettuce	*Lactuca sativa*				7.50	-1.50	400.00	2.60	2.42	264.28	792.83
Australia	Maize	*Zea mays*	16.51	1.22	-0.22	5.03	0.97	500.53	2.70	2.81	644.29	644.29
Europe[7]	Maize	*Z. mays*	11.58	1.06	-0.06	4.90	1.10	83.00	1.92	1.99	98.72	296.17
Europe[1]	Maize	*Z. mays*				7.50	-1.50	300.00	2.48	2.30	198.21	594.62
Europe[1]	Maize	*Z. mays*				7.50	-1.50	200.00	2.30	2.12	132.14	396.42
Australia	Millet	*Panicum milaceum*	16.51	1.22	-0.22	5.03	0.97	419.12	2.62	2.73	539.50	539.50
Europe[8]	Oats	*Avena sativa*	9.19	0.96	0.04	5.60	0.40	100.00	2.00	2.08	120.38	361.14
Europe[8]	Oats	*A. sativa*	24.02	1.38	-0.38	5.40	0.60	200.00	2.30	2.03	108.22	324.66
Europe[8]	Oats	*A. sativa*	5.50	0.74	0.26	5.00	1.00	200.00	2.30	2.65	448.99	1346.96
Europe[8]	Oats	*A. sativa*	11.50	1.06	-0.06	5.40	0.60	400.00	2.60	2.62	417.04	1251.11

Site	Plant species	Scientific name	CEC	Log CEC	Delta CEC	pH	Delta pH	EC10	Log EC10	Log normalised EC10	Normalised EC10	Aged normalised EC10
Europe[6]	Onion	*Allium cepa*	17.02	1.23	-0.23	8.30	-2.30	200.00	2.30	1.82	65.97	197.92
Europe[1]	Pea	*Pisum sativum (perfection)*				7.50	-1.50	400.00	2.60	2.42	264.28	792.83
Australia	Peanuts	*Arachis hypogaea*	16.51	1.22	-0.22	5.03	0.97	227.06	2.36	2.47	292.27	292.27
Australia	Peanuts	*A. hypogaea*	4.94	0.69	0.31	4.52	1.48	16.29	1.21	1.83	67.27	67.27
Europe[5]	Red clover	*Trifolium pratense*	26.42	1.42		6.20	-6.20	100.00	2.00	1.26	18.03	54.09
Europe[5]	Red clover	*T. pratense*	26.42	1.42		6.20	-0.20	84.00	1.92	1.90	79.48	238.45
Europe[5]	Red clover	*T. pratense*	12.46	1.10		5.00	1.00	32.00	1.51	1.63	42.18	126.55
Europe[5]	Red clover	*T. pratense*	3.52	0.55		5.30	0.70	32.00	1.51	1.59	38.83	116.49
Europe[9]	Red clover	*T. pratense*	3.52	0.55		5.30	0.70	32.00	1.51	1.59	38.83	116.49
Europe[9]	Red clover	*T. pratense*	3.52	0.55		5.30	0.70	32.00	1.51	1.59	38.83	116.49
Europe[1]	Spinach	*Spinacia oleracea*				7.50	-1.50	200.00	2.30	2.12	132.14	396.42
Australia	Sorghum	*Sorghum spp*	60.97	1.79	-0.79	7.26	-1.26	1660.64	3.22	2.33	212.64	212.64
Europe[1]	Sorghum	*S. bicolor var RS-626)*				7.50	-1.50	200.00	2.30	2.12	132.14	396.42
Europe[1]	Sorghum	*S. bicolor var XK-125)*				7.50	-1.50	100.00	2.00	1.82	66.07	198.21
Australia	S. cane[10]	*Saccharum*	4.94	0.69	0.31	4.52	1.48	780.00	2.89	3.51	3220.34	3220.34
Europe[1]	Tomato	*Lycopersicon esculentum*				7.50	-1.50	400.00	2.60	2.42	264.28	792.83
Australia	Triticale	*Tritosecale*	11.58	1.06	-0.06	3.96	2.04	310.18	2.49	3.00	998.11	998.11
Australia	Wheat	*Triticum aestivum*	9.95	1.00	0.00	7.63	-1.63	4764.45	3.68	3.24	1732.26	1732.26
Australia	Wheat	*T. aestivum*	3.16	0.50	0.50	5.42	0.58	91.05	1.96	2.47	293.23	293.23
Australia	Wheat	*T. aestivum*	7.82	0.89	0.11	4.39	1.61	373.62	2.57	3.08	1215.42	1215.42
Australia	Wheat	*T. aestivum*	17.71	1.25	-0.25	6.32	-0.32	1216.50	3.09	2.82	667.01	667.01
Australia	Wheat	*T. aestivum*	17.41	1.24	-0.24	5.13	0.87	1312.80	3.12	3.19	1532.36	1532.36
Australia	Wheat	*T. aestivum*	10.29	1.01	-0.01	6.33	-0.33	688.94	2.84	2.74	549.07	549.07
Australia	Wheat	*T. aestivum*	4.95	0.69	0.31	4.80	1.20	101.93	2.01	2.55	353.88	353.88
Australia	Wheat	*T. aestivum*	16.51	1.22	-0.22	5.03	0.97	262.46	2.42	2.53	337.84	337.84
Australia	Wheat	*T. aestivum*	60.97	1.79	-0.79	7.26	-1.26	2351.09	3.37	2.48	301.05	301.05
Australia	Wheat	*T. aestivum*	12.99	1.11	-0.11	4.89	1.12	428.96	2.63	2.85	715.97	715.97
Australia	Wheat	*T. aestivum*	11.58	1.06	-0.06	3.96	2.04	255.16	2.41	2.91	821.05	821.05

[1] Boawn and Rasmussen 1971; [2] Luo and Rimmer 1995; [3] Aery and Jagatiya 1997; [4] Kalyanaraman and Sivagurunathan 1993; [5] Van der Hoeven & Henzen 1994; [6] Dang et al. 1990; [7] MacLean 1974; [8] De Haan et al. 1985; [9] Hooftman and Henzen 1996; [10] sugar cane.

13.2 Appendix B. Raw toxicity data for arsenic

There are two tables in this appendix (Tables B1 and B2).

Table B1. Raw toxicity data for arsenic to plants with the corresponding toxicity values when they were converted to NOEC values.

Crop	Toxic concentration soil (mg/kg)		Reported toxic effect (%)	Interpreted toxic effect	Est. NOEC (mg/kg)	Source
	Range	Value or mean of range				
Barley		283	lower yield	LOEC	113.2	Cooper et al. 1931
Barley			90	NOEC		Davis et al. 1978
Bean	0-10	5	58-95	LOEC	2.07	Woolson 1973
Bean	<25		86	NOEC		Stewart & Smith 1922
Bean		25	lower yield	LOEC	10	Walsh & Keeney 1975
Bean		25	lower yield	LOEC	10	Sandberg& Allen1975
Bean	0-45	22.5	89	NOEC	22.5	Jacobs and Keeney 1970
Bean		140	77 (NS)	NOEC	140	Chisholm & MacPhee 1972
Bean		140	40	EC50	28	MacPhee et al. 1960
Bean		414	71	LOEC	414	Clements & Munson 1947
Blueberry		44	lower yield	LOEC	17.6	Walsh & Keeney 1975
Blueberry		70	78	LOEC	70	Anastasia & Kender 1973
Corn	10-100	55	55	EC50	11	Woolson et al. 1971
Corn		20	70	LOEC	8	Jacobs & Keeney 1970
Corn		20	90	NOEC	20	Jacobs & Keeney 1970
Corn		50	lower yield	LOEC	20	Sandberg & Allen 1975
Corn		67	24-73	EC50	13.4	Woolson et al. 1971
Corn		80	40	EC50	16	Jacobs & Keeney 1970
Corn		90	91	NOEC	90	Jacobs et al. 1970
Corn		100	86	NOEC	100	Woolson 1972
Corn		125	lower yield	LOEC	50	Sandberg & Allen 1975
Cotton		25	48	EC50	5	Deuel & Swoboda 1972
Cotton		50	lower yield	LOEC	20	Ray 1975
Cotton		50	lower yield	LOEC	20	Ray 1975
Cotton		125	60	EC50	25	Deuel & Swoboda 1972
Cotton		196	lower yield	LOEC	78.4	Ray 1975
Grass		3.2	5	EC95		Millhollon 1970
Grass		45	0-25	LOEC	18	Weaver et al. 1984
Grass		90	50	EC50	18	Weaver et al. 1984
Grass		104	88	NOEC	104	Clements & Munson 1947
Oat	0-10	5	78	NOEC	5	Woolson et al. 1971
Oat	0-10	5	94	NOEC	5	Woolson et al. 1971
Oat		100	2	EC98		Jacobs et al. 1970
Oat	40-290	165	5	EC95		Rosenfels & Crafts 1940
Oat		50	90	NOEC	50	Sandberg & Allen 1975
Oat	160-340	250	5	EC95		Rosenfels & Crafts 1940
Oat		188	lower yield	LOEC	75.2	Cooper et al. 1931
Oat	280-590	435	5	EC95		Rosenfels & Crafts 1940
Oat	540-850	695	5	EC95		Rosenfels & Crafts 1940
Pea	11-14	12.5	90	NOEC	12.5	Steevens et al. 1972
Pea		25	lower yield	LOEC	10	Walsh & Keeney 1975
Pea	25-75	50	85	NOEC	50	Stewart & Smith 1922

Crop	Toxic concentration soil (mg/kg)		Reported toxic effect (%)	Interpreted toxic effect	Est. NOEC (mg/kg)	Source
	Range	Value or mean of range				
Pea	0-45	22.5	90	NOEC	22.5	Jacobs and Keeney 1970
Pea		140	50	EC50	28	MacPhee et al. 1960
Pine	>200	200	lethal	NOEC	200	Sheppard et al. 1985
Pine	>250	250	lethal	NOEC	250	Sheppard et al. 1985
Pine	>500	500	no effect	NOEC	500	Sheppard et al. 1985
Potato	45-73	59	85	NOEC	59	Sheppard et al. 1985
Potato		68	lower yield	LOEC	27.2	Walsh & Keeney 1975
Potato		75	33	EC50	15	Stewart & Smith 1922
Potato		180	79	LOEC	72	Jacobs and Keeney 1970
Radish		2.5	lower yield	LOEC	6.33	Hiltbold 1975
Radish	10-100	55	23-93	EC50	11	Woolson 1973
Radish		15	89	NOEC	15	Sheppard et al. 1985
Radish		36	52	EC50	7.2	Woolson & Isensee 1981
Radish		390	82	NOEC	390	Sheppard et al. 1982
Radish		500	86	NOEC	500	Stewart & Smith 1922
Sedge		1.8	lower yield	LOEC	0.72	Hiltbold 1975
Soyabean		12.5	55	EC50	2.5	Deuel & Swoboda 1972
Soyabean		34	lower yield	LOEC	13.6	Raab 1972a, 1972b
Soyabean		37	65	LOEC	14.8	Woolson & Isensee 1981
Soyabean		50	61	EC40	10	Sandberg & Allen 1975
Soyabean		84	60	EC40	16.8	Deuel & Swoboda 1972
Tomato	0-10	5	77-94	NOEC	8.47	Woolson et al. 1973
Tomato		140	76	LOEC	56	MacPhee et al. 1960
Tomato		514	90	NOEC	514	Clements & Munson 1947
Wheat		94	lower yield	LOEC	37.6	Cooper et al. 1981
Wheat		250	63	LOEC	100	Stewart & Smith 1922

Table B2. Raw toxicity data for arsenic to soil invertebrates and terrestrial mammals with the corresponding toxicity values when they were converted to NOEC values.

Common name	Scientific name	Measure of toxicity	Toxicity data (mg/kg)	Est. EC10	Source:
Common rat	Rattus norvegicus	NOEC	10	10	US EPA 2007
Deer mouse	*Peromyscus maniculatus*	EC50	1600	320	US EPA 2007
Earthworm	*Eisenia fetida*	EC50	100	20	Langdon et al. 2003
Earthworm	*Lumbriculus rubellus*	EC50	1510	302	Langdon et al. 2001
Earthworm	*L. rubellus*	EC50	96	19.2	Langdon et al. 2001
Earthworm	*L. terrestris*	NOEC	100	100	Meharg et al. 1998
Earthworm	*L. terrestris*	NOEC	100	100	Meharg et al. 1998
Fulvous whistling-duck	*Dendrocygna bicolor*	EC50	1145	229	Kegley et al. 2008
Northern bobwhite	*Colinus virginianus*	EC50	168.5	33.7	Kegley et al. 2008
Northern bobwhite	*C. virginianus*	EC50	432	86.4	Kegley et al. 2008
Sheep	*Ovis aries*	NOEC	25	25	US EPA, 2007

13.3 Appendix C: Raw toxicity data for naphthalene

There are two tables in this appendix (Tables C1 and C2).

Table C1. Raw data for naphthalene where the toxicity was expressed in terms of mg/kg.

Test species		Measure of toxicity	Toxic conc. (mg/kg)	Source:
Common name	**Scientific name**			
Common rat	*Rattus norvegicus*	NOEC	1000	US EPA 2007
Earthworm	*Eisenia fetida*	EC25	54	CCME 1999b
European rabbit	*Oryctolagus cuniculus*	NOEC	2000	US EPA 2007
House mouse	*Mus musculus*	LD10	320	US EPA 2007
House mouse	*M. musculus*	LD10	518	US EPA 2007
Lettuce	*Lactuca sativa*	NOEC	100	Adema & Henzen 2001
Lettuce	*L. sativa*	NOEC	32	Adema & Henzen 2001
Lettuce	*L. sativa*	NOEC	100	Adema & Henzen 2001
Lettuce	*L. sativa*	NOEC	3.2	Adema & Henzen 2001
Lettuce	*L. sativa*	NOEC	32	Adema & Henzen 2001
Lettuce	*L. sativa*	EC25	3	CCME 1999b
Northern bobwhite	*Colinus virginianus*	NOEC	1000	US EPA 2007
Northern bobwhite	*C. virginianus*	NOEC	1000	US EPA 2007
Northern bobwhite	*C. virginianus*	LD50	538	US EPA 2007
Radish	*Raphanus sativa*	EC25	61	CCME 1999b
Springtail	*Folsomia fimetaria*	EC10	20	Sverdrup et al. 2002

Table C2. Raw toxicity data for naphthalene that caused a 50% effect (EC50) and were expressed in terms of g/m², the corresponding value expressed in terms of mg/kg, the corresponding EC10 or NOEC values and the source of the original data.

Test species		EC50 (g/m^2)	EC50 (mg/kg)	Estimated NOEC or EC10 (mg/kg)	Source
Common name	Scientific name				
Mite	*Acari sp.*	13	1000	200	Best et al. 1978
Mite	*Acari sp.*	11	846	169	Best et al. 1978
Mite	*Acari sp.*	24	1846	369	Best et al. 1978
Mite	*Mesostigmata sp.*	10	769	154	Best et al. 1978
Mite	*Mesostigmata sp.*	16	1231	246	Best et al. 1978
Mite	*Oribatida sp.*	10	769	153	Best et al. 1978
Mite	*Oribatida sp.*	24	1846	369	Best et al. 1978
Mite	*Oribatida sp.*	12	923	185	Best et al. 1978
Spider	*Grammonota inornata*	9	692	138	Best et al. 1978
Spider	*G. inornata*	17	1308	262	Best et al. 1978
Spider	*G. inornata*	10	769	154	Best et al. 1978
Springtail	*Collembola sp.*	8	615	123	Best et al. 1978
Springtail	*Collembola sp.*	21	1615	323	Best et al. 1978
Springtail	*Collembola sp.*	16	1231	246	Best et al. 1978
Springtail	*Poduromorpha sp.*	18	1385	277	Best et al. 1978
Springtail	*Poduromorpha sp.*	16	1231	246	Best et al. 1978
Springtail	*Poduromorpha sp.*	8	615	123	Best et al. 1978

13.4 Appendix D: Raw toxicity data for DDT

Table D1. The raw toxicity data for DDT that measured a variety of toxic effects, the estimated NOEC or EC10 value and the source.

Test species		Measure of toxicity	Toxic conc. (mg/kg)	Est. NOEC or EC10 (mg/kg)	Source
Common name	Scientific name				
Earthworm	*Eisenia fetida*	EC10	47.7	47.7	Hund-Rindke & Simon 2005
Earthworm	*E. fetida*	NOEC	1000	1000	Hund-Rindke & Simon 2005
Earthworm	*E. fetida*	NOEC	1000	1000	Hund-Rindke & Simon 2005
Field mustard	*Brassica rapa*	NOEC	1000	1000	Hund-Rindke & Simon 2005
Field mustard	*B. rapa*	NOEC	1000	1000	Hund-Rindke & Simon 2005
Field mustard	*B. rapa*	NOEC	1000	1000	Hund-Rindke & Simon 2005
Helmeted guineafowl	*Numida meleagris*	LOEL	75	30	US EPA 2007
House sparrow	*Passer domesticus*	LOEL	1500	600	US EPA 2007
Japanese quail	*Coturnix japonica*	LOEL	200	80	US EPA 2007
Mallard duck	*Anas platyrhynchos*	LOEL	59.5	23.8	US EPA 2007
Northern bobwhite	*Colinus virginianus*	NOEC	50	50	US EPA 2007
Northern bobwhite	*C. virginianus*	LOEL	232	92.8	US EPA 2007
Oats	*Avena sativa*	NOEC	1000	1000	Hund-Rindke & Simon 2005
Oats	*A. sativa*	NOEC	1000	1000	Hund-Rindke & Simon 2005
Oats	*A. sativa*	NOEC	1000	1000	Hund-Rindke & Simon 2005
Ring-necked pheasant	*Phasianus colchicus*	LC50	522	104	US EPA 2007
Soil process	Ammonification	EC12	1250	1250	CCME 1999
Soil process	Nitrification	EC36	1000	400	CCME 1999
Soil process	Nitrification	EC31	12.5	5	CCME1999
Soil process	Nitrification	EC24	50	50	CCME 1999
Soil process	Nitrification	EC22	100	100	CCME 1999
Soil process	Potential ammonium oxidation	NOEC	1000	1000	Hund-Rindke & Simon 2005
Soil process	Potential ammonium oxidation	NOEC	1000	1000	Hund-Rindke & Simon 2005
Soil process	Potential ammonium oxidation	NOEC	1000	1000	Hund-Rindke & Simon 2005
Soil process	Respiration	NOEC	1000	1000	Hund-Rindke & Simon 2005
Soil process	Respiration	NOEC	1000	1000	Hund-Rindke & Simon 2005
Soil process	Respiration	NOEC	1000	1000	Hund-Rindke & Simon 2005
Soil process	SIR	NOEC	1000	1000	Hund-Rindke & Simon 2005
Soil process	SIR	NOEC	1000	1000	Hund-Rindke & Simon 2005
Soil process	SIR	NOEC	1000	1000	Hund-Rindke & Simon 2005
Springtail	*Folsomia candida*	EC10	99.9	99.9	Hund-Rindke & Simon 2005
Springtail	*F. candida*	NOEC	1000	1000	Hund-Rindke & Simon 2005
Springtail	*F. candida*	NOEC	1000	1000	Hund-Rindke & Simon 2005

13.5 Appendix E: Raw toxicity data for copper

Table E1. The raw toxicity data for copper and the ageing leaching factor that were used in the derivation of the soil quality guidelines derived in this project and the source of the toxicity data.

Species	Endpoint	NOEC or EC10 added (mg/kg)	LOEC and EC30 (mg/kg)	EC50 added (mg/kg)	ALF	Reference
Andryala integrifolia	mortality	76	106	130	2	Brun et al. 2003
Andryala integrifolia	seedling emergence	78	106	128	2	Brun et al. 2003
Arachis hypogaea	grain yield	398		467	1	Barry and Bell 2006
Arachis hypogaea	grain yield	197		516	1	Barry and Bell 2006
Avena sativa	yield grain	200	300	600	2	De Haan et al. 1985
Avena sativa	yield grain	200	300	600	2	De Haan et al. 1985
Avena sativa	yield grain	200	300	600	2	De Haan et al. 1985
Avena sativa	yield grain	200	300	600	2	De Haan et al. 1985
Avena sativa	yield grain	200	300	600	2	De Haan et al. 1985
Brassica napus	grain yield	1310	1965	1370	1	Heemsbergen et al. 2007
Brassica napus	grain yield	926	1136	1566	1	NBRP unpublished data
Brassica napus	grain yield	315	473	452	1	Butler et al. 2007
Gossypium sp.	crop yield	1451	2177	1757	1	Barry and Bell 2006
Hordeum vulgare	grain yield	77	116	720	1	Heemsbergen et al. 2007
Hordeum vulgare	grain yield	313	470	1300	1	Heemsbergen et al. 2007
Hordeum vulgare	grain yield	222	333	645	1	Heemsbergen et al. 2007
Hordeum vulgare	grain yield	49	74	515	1	Butler et al. 2007
Hordeum vulgare	grain yield	28	41	227	1	Butler et al. 2007

Hordeum vulgare	seedling emergence	112	305	335	2	Ali et al. 2004
Hordeum vulgare	shoot weight	305	>304.8	914	2	Ali et al. 2004
Hordeum vulgare	root weight	3	11	305	2	Ali et al. 2004
Hordeum vulgare	yield roots	58	87	137	2	Rooney et al. 2006
Hordeum vulgare	yield roots	16	24	36	2	Rooney et al. 2006
Hordeum vulgare	yield roots	85	128	173	2	Rooney et al. 2006
Hordeum vulgare	yield roots	80	120	233	2	Rooney et al. 2006
Hordeum vulgare	yield roots	45	68	536	2	Rooney et al. 2006
Hordeum vulgare	yield roots	14	21	40	2	Rooney et al. 2006
Hordeum vulgare	yield roots	83	125	161	2	Rooney et al. 2006
Hordeum vulgare	yield roots	20	30	56	2	Rooney et al. 2006
Hordeum vulgare	yield roots	35	53	129	2	Rooney et al. 2006
Hordeum vulgare	yield roots	144	216	376	2	Rooney et al. 2006
Hordeum vulgare	yield roots	69	104	187	2	Rooney et al. 2006
Hordeum vulgare	yield roots	53	80	359	2	Rooney et al. 2006
Hordeum vulgare	yield roots	77	116	252	2	Rooney et al. 2006
Hordeum vulgare	yield roots	120	180	405	2	Rooney et al. 2006
Hordeum vulgare	yield roots	96	144	344	2	Rooney et al. 2006
Hordeum vulgare	yield roots	111	167	326	2	Rooney et al. 2006
Hordeum vulgare	yield roots	98	147	375	2	Rooney et al. 2006
Hordeum vulgare	yield roots	26	39	114	2	Rooney et al. 2006
Hypochoeris radicata	mortality	99	165	227	2	Brun et al. 2003
Hypochoeris radicata	reproduction	157	173	187	2	Brun et al. 2003
Hypochoeris radicata	seedling emergence	175	187	195	2	Brun et al. 2003
Lolium perenne	yield shoots	95	513	1036	2	Jarvis 1978
Lolium perenne	yield roots	95	831	947	2	Jarvis 1978

Lycopersicon esculentum	yield shoots	46	69	130	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	159	239	427	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	370	555	829	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	48	72	115	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	29	44	61	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	89	134	237	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	179	269	281	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	598	897	851	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	252	378	351	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	311	467	933	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	481	722	795	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	212	318	771	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	212	318	659	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	251	377	444	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	116	174	429	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	70	105	325	2	Rooney et al. 2006
Lycopersicon esculentum	yield shoots	175	300	600	2	Rhoads et al. 1989
Lycopersicon esculentum	yield shoots	350	700	1400	2	Rhoads et al. 1989
Lycopersicon esculentum	yield shoots	350	700	1400	2	Rhoads et al. 1989
Panicum milaceum	yield	206	309	389	1	Barry and Bell 2006
Poa annua	mortality	200	389	418	2	Brun et al. 2003
Poa annua	reproduction	200	216	262	2	Brun et al. 2003
Poa annua	seedling emergence	100	91	141	2	Brun et al. 2003
Polygonum convolvulus	yield (total dm)	188	237	276	2	Kjær and Elmegaard 1996
Polygonum convolvulus	yield (total dm)	188	301	309	2	Kjær and Elmegaard 1996
Polygonum convolvulus	reproductive dry matter	188	222	251	2	Kjær and Elmegaard 1996
Polygonum convolvulus	reproductive dry matter	188	247	287	2	Kjær and Elmegaard 1996
Polygonum convolvulus	seed biomass	188	303	327	2	Kjær and Elmegaard 1996

Polygonum convolvulus	mortality	113	211	257	2	Kjær and Elmegaard 1996
Polygonum convolvulus	mortality	113	188	387	2	Kjær and Elmegaard 1996
Polygonum convolvulus	yield shoots	200	300	259	2	Pedersen et al. 2000
Polygonum convolvulus	yield roots	200	300	291	2	Pedersen et al. 2000
Sacharum sp.	yield	203	305	342	1	Barry and Bell 2006
Senecio vulgaris	mortality	78	150	228	2	Brun et al. 2003
Senecio vulgaris	reproduction	156	173	184	2	Brun et al. 2003
Senecio vulgaris	seedling emergence	28	57	88	2	Brun et al. 2003
Sorghum sp.	yield	598	897	1433	1	Barry and Bell 2006
Sorghum sp.	yield	206	309	318	1	Barry and Bell 2006
Triticum aestivum	grain yield	1133	1139	1147	1	Warne et al. 2008
Triticum aestivum	grain yield	132	176	286	1	Warne et al. 2008
Triticum aestivum	grain yield	731	1561	5705	1	Warne et al. 2008
Triticum aestivum	grain yield	148	228	476	1	Warne et al., 2008
Triticum aestivum	grain yield	284	385	649	1	Warne et al. 2008
Triticum aestivum	grain yield	130	157	212	1	Warne et al. 2008
Triticum aestivum	grain yield	209	242	310	1	Warne et al. 2008
Triticum aestivum	grain yield	787	1316	3170	1	Warne et al. 2008
Triticum aestivum	grain yield	586	603	632	1	Warne et al. 2008
Triticum aestivum	grain yield	622	752	1040	1	Warne et al. 2008
Triticum aestivum	grain yield	473	768	1760	1	Warne et al. 2008
Triticum aestivum	8wk plant biomass	3	36	2070	1	Warne et al. 2008
Triticum aestivum	8wk plant biomass	351	360	375	1	Warne et al. 2008
Triticum aestivum	8wk plant biomass	635	792	1154	1	Warne et al. 2008
Triticum aestivum	8wk plant biomass	117	168	315	1	Warne et al. 2008

Triticum aestivum	8wk plant biomass	193	220	272	1	Warne et al. 2008
Triticum aestivum	8wk plant biomass	144	233	526	1	Warne et al. 2008
Triticum aestivum	8wk plant biomass	40	75	223	1	Warne et al. 2008
Triticum aestivum	8wk plant biomass	1100	1128	1183	1	Warne et al. 2008
Triticum aestivum	8wk plant biomass	52	102	330	1	Warne et al. 2008
Tritosecale sp.	yield	481	1020	2040	1	Butler et al. 2007
Zea mays	yield	274		363	1	Barry and Bell 2006
Cognettia sphagnetorum	growth	20	50	91	2	Augustsson and Rundgren 1998
Cognettia sphagnetorum	growth	63	85	167	2	Augustsson and Rundgren 1998
Cognettia sphagnetorum	growth	441	502	605	2	Augustsson and Rundgren 1998
Cognettia sphagnetorum	growth	312	435	557	2	Augustsson and Rundgren 1998
Cognettia sphagnetorum	fragmenattion	455	538	676	2	Augustsson and Rundgren 1998
Cognettia sphagnetorum	fragmenattion	23	82		2	Augustsson and Rundgren 1998
Eisenia andrei	growth	56	84	168	2	Van Dis et al. 1988
Eisenia andrei	growth	56	84	168	2	Van Gestel et al. 1991
Eisenia andrei	reproduction	120	180	360	2	Van Gestel et al. 1989
Eisenia andrei	reproduction	100	223	327	2	Kula and Larink 1997
Eisenia andrei	reproduction	100	168	240	2	Kula and Larink 1997
Eisenia andrei	reproduction	3	45	79	2	Kula and Larink 1997
Eisenia andrei	reproduction	154			2	Criel et al. 2008
Eisenia andrei	reproduction	88	188	264	2	Svendsen & Weeks 1997a
Eisenia andrei	mortality	188	335	564	2	Svendsen & Weeks 1997a
Eisenia fetida	mortality	208	311	555	2	Spurgeon et al. 1994
Eisenia fetida	mortality	293	440	836	2	Spurgeon and Hopkin 1995
Eisenia fetida	growth	725	1088	601	2	Spurgeon and Hopkin 1995
Eisenia fetida	growth	700	1000		2	Scott-Fordsmand et al. 2000b

Eisenia fetida	reproduction	30	44	51	2	Spurgeon et al. 1994
Eisenia fetida	reproduction	29	44	87	2	Spurgeon and Hopkin 1995
Eisenia fetida	reproduction	10	132	174	2	Kula and Larink 1997
Eisenia fetida	reproduction	32	72	108	2	Kula and Larink 1997
Eisenia fetida	reproduction	2	13	42	2	Kula and Larink 1997
Eisenia fetida	reproduction	0	3	10	2	Kula and Larink 1997
Eisenia fetida	reproduction	100	300	210	2	Scott-Fordsmand et al. 2000b
Eisenia fetida	reproduction	161	243	190	2	Criel et al. 2008
Eisenia fetida	reproduction	84	172	211	2	Criel et al. 2008
Eisenia fetida	reproduction	120	92	708	2	Criel et al. 2008
Eisenia fetida	reproduction	86	100	171	2	Criel et al. 2008
Eisenia fetida	reproduction	88	289	296	2	Criel et al. 2008
Eisenia fetida	reproduction	67	165	198	2	Criel et al. 2008
Eisenia fetida	reproduction	31	94	67	2	Criel et al. 2008
Eisenia fetida	reproduction	213	464	329	2	Criel et al. 2008
Eisenia fetida	reproduction	195	237	230	2	Criel et al. 2008
Eisenia fetida	reproduction	279	538	487	2	Criel et al. 2008
Eisenia fetida	reproduction	151	501	267	2	Criel et al. 2008
Eisenia fetida	reproduction	346	501	407	2	Criel et al. 2008
Eisenia fetida	reproduction	148	281	309	2	Criel et al. 2008
Eisenia fetida	reproduction	454	258	731	2	Criel et al. 2008
Eisenia fetida	reproduction	188	160	358	2	Criel et al. 2008
Eisenia fetida	reproduction	69	153	149	2	Criel et al. 2008
Eisenia fetida	reproduction	223	361	347	2	Criel et al. 2008
Lumbricus rubellus	mortality	150	224	486	2	Svendsen & Weeks 1997b
Lumbricus rubellus	mortality	117	344	393	2	Ma 1984
Lumbricus rubellus	mortality	123	359	408	2	Ma 1984
Lumbricus rubellus	mortality	150		459	2	Ma 1982
Lumbricus rubellus	mortality	447	521	1384	2	Spurgeon et al. 2004
Lumbricus rubellus	litter breakdown	40	123	162	2	Ma 1984
Lumbricus rubellus	litter breakdown	50	168	189	2	Ma 1984

Lumbricus rubellus	growth	117	358	393	2	Ma 1984
Lumbricus rubellus	growth	73	150	228	2	Svendsen & Weeks 1997b
Lumbricus rubellus	growth	140	642	462	2	Spurgeon et al. (2004)
Lumbricus rubellus	reproduction	40	97	162	2	Ma 1984
Plectus acuminatus	reproduction	32	100	300	2	Kammenga et al. 1996
Folsomia candida	reproduction	190	299	260	2	Criel et al. 2008
Folsomia candida	reproduction	10	49	43	2	Criel et al. 2008
Folsomia candida	reproduction	417	530	952	2	Criel et al. 2008
Folsomia candida	reproduction	1380	2070	2200	2	Criel et al. 2008
Folsomia candida	reproduction	50	75	166	2	Criel et al, 2008
Folsomia candida	reproduction	51	85	112	2	Criel et al. 2008
Folsomia candida	reproduction	206	314	325	2	Criel et al. 2008
Folsomia candida	reproduction	186	489	325	2	Criel et al. 2008
Folsomia candida	reproduction	618	551	1238	2	Criel et al. 2008
Folsomia candida	reproduction	195	285	510	2	Criel et al. 2008
Folsomia candida	reproduction	659	803	862	2	Criel et al. 2008
Folsomia candida	reproduction	80	291	434	2	Criel et al. 2008
Folsomia candida	reproduction	1186	1666	1626	2	Criel et al. 2008
Folsomia candida	reproduction	550	707	845	2	Criel et al. 2008
Folsomia candida	reproduction	200	311	640	2	Criel et al. 2008
Folsomia candida	reproduction	683	1629	1199	2	Criel et al. 2008
Folsomia candida	reproduction	686	919	835	2	Criel et al. 2008
Folsomia candida	reproduction	227	1049	632	2	Criel et al. 2008
Folsomia candida	reproduction	16	37	73	2	Criel et al. 2008
Folsomia candida	reproduction	797		813	2	Herbert et al. 2004
Folsomia candida	reproduction	198	411	650	2	Sandifer & Hopkin 1996
Folsomia candida	reproduction	231	486	774	2	Sandifer & Hopkin 1996
Folsomia candida	reproduction	920	1083	1200	2	Sandifer & Hopkin 1996
Folsomia candida	reproduction	200	300	700	2	Sandifer & Hopkin 1997
Folsomia candida	reproduction	200	300	640	2	Sandifer & Hopkin 1997
Folsomia candida	reproduction	400	600	1200	2	Rundgren and Van Gestel 1988
Folsomia candida	reproduction	400	600	1200	2	Rundgren and Van Gestel 1988

Folsomia candida	mortality	1281		1821	2271	2	Sandifer & Hopkin 1997
Folsomia candida	mortality	387		981	1761	2	Sandifer & Hopkin 1997
Folsomia candida	mortality	135		676	1859	2	Sandifer & Hopkin 1997
Folsomia candida	mortality	135		676		2	Sandifer & Hopkin 1996
Folsomia candida	mortality	561		1586		2	Sandifer & Hopkin 1996
Folsomia candida	mortality	2657		2978		2	Sandifer & Hopkin 1996
Folsomia candida	growth	800		1200	2400	2	Rundgren and Van Gestel 1988
Folsomia candida	growth	200		300	600	2	Rundgren and Van Gestel 1988
Folsomia fimetaria	mortality	878		1000	2000	2	Scott-Fordsmand et al. 1997
Folsomia fimetaria	mortality	1000	>1000		3000	2	Scott-Fordsmand et al. 1997
Folsomia fimetaria	mortality	1000	>1000		3000	2	Scott-Fordsmand et al. 1997
Folsomia fimetaria	growth	542		400	800	2	Scott-Fordsmand et al. 1997
Folsomia fimetaria	growth	845		800	1600	2	Scott-Fordsmand et al. 1997
Folsomia fimetaria	growth	527		600	1200	2	Scott-Fordsmand et al. 1997
Folsomia fimetaria	reproduction	38		57	113	2	Scott-Fordsmand et al. 1997
Folsomia fimetaria	reproduction	122		183	638	2	Pedersen et al. 2000
Folsomia fimetaria	reproduction	698		1047	1225	2	Pedersen et al. 2001
Folsomia fimetaria	reproduction	776		1164	1635	2	Pedersen et al. 2001
Folsomia fimetaria	reproduction	888		1332	1674	2	Pedersen et al. 2001
Folsomia fimetaria	reproduction	648		972	1259	2	Pedersen et al. 2001
Folsomia fimetaria	reproduction	688		1032	1395	2	Pedersen et al.,2001
Hypoaspis aculeifer	reproduction	174		261	522	2	Krogh and Axelsen 1998
Isotoma viridis	growth	50		75	150	2	Rundgren and Van Gestel 1988
Isotoma viridis	growth	400		600	1200	2	Rundgren and Van Gestel 1988
Platynothrus peltifer	reproduction	63		95	189	2	Van Gestel and Doornekamp 1998
Platynothrus peltifer	reproduction	63		95	189	2	Van Gestel and Doornekamp 1998
Platynothrus peltifer	reproduction	63		95	189	2	Van Gestel and Doornekamp 1998

Soil microbial process	microbial biomass C		118	268	354	2	Khan and Scullion 2002
Soil microbial process	microbial biomass C		118	268	354	2	Khan and Scullion 2002
Soil microbial process	microbial biomass N		468	768	1404	2	Khan and Scullion 2002
Soil microbial process	microbial biomass N	<118		118	236	2	Khan and Scullion 2002
Soil microbial process	SIR[1]		635	953	1905	2	Speir et al. 1999
Soil microbial process	SIR		635	953	1905	2	Speir et al. 1999
Soil microbial process	SIR		1200	1800	3600	2	University of Leuven 2004
Soil microbial process	SIR		150	225	450	2	University of Leuven 2004
Soil microbial process	SIR		50	75	150	2	University of Leuven 2004
Soil microbial process	SIR		600	900	1800	2	University of Leuven 2004
Soil microbial process	SIR		100	150	300	2	University of Leuven 2004
Soil microbial process	SIR		25	38	75	2	University of Leuven 2004
Soil microbial process	SIR		100	150	300	2	University of Leuven 2004
Soil microbial process	SIR		50	75	150	2	University of Leuven 2004
Soil microbial process	SIR		25	38	75	2	University of Leuven 2004
Soil microbial process	SIR		400	600	1200	2	University of Leuven 2004
Soil microbial process	SIR		300	450	900	2	University of Leuven 2004
Soil microbial process	SIR		50	75	150	2	University of Leuven 2004
Soil microbial process	SIR		102	153	306	2	University of Leuven 2004
Soil microbial process	SIR		200	300	600	2	University of Leuven 2004
Soil microbial process	SIR		89	134	267	2	University of Leuven 2004
Soil microbial process	SIR		23	35	69	2	University of Leuven 2004
Soil microbial process	SIR		300	450	900	2	University of Leuven 2004
Soil microbial process	SIR		200	300	600	2	University of Leuven 2004
Soil microbial process	SIR		50	75	150	2	University of Leuven 2004
Soil microbial process	SIR		170	255	510	2	University of Leuven 2004
Soil microbial process	SIR		12	18	36	2	University of Leuven 2004
Soil microbial process	SIR		25	38	75	2	University of Leuven 2004
Soil microbial process	SIR		100	150	300	2	University of Leuven 2004
Soil microbial process	SIR		27	41	81	2	University of Leuven 2004
Soil microbial process	SIR		185	345	1000	1	Broos et al. 2007
Soil microbial process	SIR		3	31	1078	1	Broos et al. 2007

Soil microbial process	SIR	326	450	555	1	Broos et al. 2007
Soil microbial process	SIR	230	496	1842	1	Broos et al. 2007
Soil microbial process	SIR	255	503	1606	1	Broos et al. 2007
Soil microbial process	SIR	48	134	784	1	Broos et al. 2007
Soil microbial process	SIR	39	111	662	1	Broos et al. 2007
Soil microbial process	SIR	222	559	2321	1	Broos et al. 2007
Soil microbial process	SIR	202	421	1478	1	Broos et al. 2007
Soil microbial process	SIR	26	73	431	1	Broos et al. 2007
Soil microbial process	SIR	134	259	795	1	Broos et al. 2007
Soil microbial process	SIR	25	97	940	1	Broos et al. 2007
Soil microbial process	GAD[2]	55	400	800	1	Haanstra & Doelman 1984
Soil microbial process	GAD	55	400	800	1	Haanstra & Doelman 1984
Soil microbial process	GAD	400	1000	2000	1	Haanstra & Doelman 1984
Soil microbial process	MRR[3]	2400	3600	7200	2	University of Leuven 2004
Soil microbial process	MRR	1200	1800	3600	2	University of Leuven 2004
Soil microbial process	MRR	1200	1800	3600	2	University of Leuven 2004
Soil microbial process	MRR	300	450	900	2	University of Leuven 2004
Soil microbial process	MRR	50	75	150	2	University of Leuven 2004
Soil microbial process	MRR	200	300	600	2	University of Leuven 2004
Soil microbial process	MRR	100	150	300	2	University of Leuven 2004
Soil microbial process	MRR	50	75	150	2	University of Leuven 2004
Soil microbial process	MRR	400	600	1200	2	University of Leuven 2004
Soil microbial process	MRR	150	225	450	2	University of Leuven 2004
Soil microbial process	MRR	50	75	150	2	University of Leuven 2004
Soil microbial process	MRR	400	600	1200	2	University of Leuven 2004
Soil microbial process	MRR	600	900	1800	2	University of Leuven 2004
Soil microbial process	MRR	150	225	450	2	University of Leuven 2004
Soil microbial process	MRR	150	225	450	2	University of Leuven 2004
Soil microbial process	MRR	51	77	153	2	University of Leuven 2004
Soil microbial process	MRR	83	125	249	2	University of Leuven 2004
Soil microbial process	MRR	100	150	300	2	University of Leuven 2004
Soil microbial process	MRR		144	288	2	Oorts et al. 2006a
Soil microbial process	MRR		348	696	2	Oorts et al. 2006a

Soil microbial process	MRR		802	1604	2	Oorts et al. 2006a
Soil microbial process	respiration	89	1402	7932	1	Doelman & Haanstra 1984
Soil microbial process	respiration	400	600	1200	1	Doelman & Haanstra 1984
Soil microbial process	respiration	493	4097	15477	1	Doelman & Haanstra 1984
Soil microbial process	respiration	32	219	730	1	Doelman & Haanstra 1984
Soil microbial process	PNR[4]	200	300	400	2	University of Leuven 2004
Soil microbial process	PNR	1200	1800	2400	2	University of Leuven 2004
Soil microbial process	PNR	25	38	50	2	University of Leuven 2004
Soil microbial process	PNR	25	38	50	2	University of Leuven 2004
Soil microbial process	PNR	50	75	100	2	University of Leuven 2004
Soil microbial process	PNR	100	150	200	2	University of Leuven 2004
Soil microbial process	PNR	300	450	600	2	University of Leuven 2004
Soil microbial process	PNR	200	300	400	2	University of Leuven 2004
Soil microbial process	PNR	800	1200	1600	2	University of Leuven 2004
Soil microbial process	PNR	400	600	800	2	University of Leuven 2004
Soil microbial process	PNR	600	900	1200	2	University of Leuven 2004
Soil microbial process	PNR	800	1200	1600	2	University of Leuven 2004
Soil microbial process	PNR	300	450	600	2	University of Leuven 2004
Soil microbial process	PNR	400	600	800	2	University of Leuven 2004
Soil microbial process	PNR	52	78	104	2	University of Leuven 2004
Soil microbial process	PNR	127	191	254	2	University of Leuven 2004
Soil microbial process	PNR	65	98	130	2	University of Leuven 2004
Soil microbial process	PNR	100	150	200	2	University of Leuven 2004
Soil microbial process	PNR	50	75	100	2	University of Leuven 2004
Soil microbial process	PNR			771	2	Oorts et al. 2006a
Soil microbial process	PNR			677	2	Oorts et al. 2006a
Soil microbial process	SIN[6]	100	150	200	2	Quraishi & Cornfield 1973
Soil microbial process	SIN	100	150	200	2	Quraishi & Cornfield 1973
Soil microbial process	SIN	1000	1500	2000	2	Premi & Cornfield 1969
Soil microbial process	SIN	2594	2594	2594	1	Broos et al. 2007
Soil microbial process	SIN	34	254	1078	1	Broos et al. 2007
Soil microbial process	SIN	206	208	211	1	Broos et al. 2007

Soil microbial process	SIN	1271	1451	1821	1	Broos et al. 2007
Soil microbial process	SIN	175	228	355	1	Broos et al. 2007
Soil microbial process	SIN	1	5	59	1	Broos et al. 2007
Soil microbial process	SIN	47	70	140	1	Broos et al. 2007
Soil microbial process	SIN	383	502	797	1	Broos et al. 2007
Soil microbial process	SIN	887	914	964	1	Broos et al. 2007
Soil microbial process	SIN	919	932	953	1	Broos et al. 2007
Soil microbial process	SIN	502	571	712	1	Broos et al. 2007
Soil microbial process	SIN	141	225	497	1	Broos et al. 2007
Soil microbial process	N-mineralisation	100	150	300	2	Quraishi & Cornfield 1973
Soil microbial process	N-mineralisation	268	465	804	2	Khan and Scullion 2002
Soil microbial process	N-mineralisation		115	230	2	Khan and Scullion 2002
Soil microbial process	ammonification	1000	1500	3000	2	Premi & Cornfield 1969
Soil microbial process	denitrification	100	250	300	2	Bollag & Barabasz 1979

[1] SIR = substrate induced nitrification, [2] GAD = glutamic acid decomposition, [3] MRR = maize residue respiration, [4] PNR = potential nitrification rate, [5] SIN = substrate induced respiration.

13.6 Appendix F: Explanation of the selection of the soil properties that control the added contaminant limits for copper

A total of ten normalisation relationships were used to normalise the Cu toxicity data. The same ten normalistion relationships were used to generate the soil-specific ACLs. The generated soil-specific ACLs are the concentrations for each species/soil process that correspond to the desired level of protection (for example, 80% for urban residential land/public open space use). Therefore, in order to provide the desired level of protection, the lowest ACL at each soil property value must be adopted as the final ACL.

For Cu there were six normalisation relationships based on CEC. These were for *H. vulgare, L. escultentum, E. fetida, F. candida, F. fimetaria* and PNR. Of these, PNR always generated the lowest ACL when the CEC was less than 10 $cmol_c$/kg. At all higher CEC values the *H. vulgare* normalisation relationship always resulted in the lowest ACL. Therefore, one set of soil-specific ACLs was generated by for *H. vulgare* and another for PNR with the lowest of the two at each CEC being adopted as the CEC-based ACL values for Cu.

In addition, there was one normalisation relationship based on a combination of soil pH and organic carbon content (OC) — for *T. aestivum*. There were also two normalisation relationships for SIN and MRM that were based on soil pH and one for SIR based on OC. The MRM normalisation relationship was not used as it had a negative relationship with toxicity which was inconsistent with all the other normalisation relationships for Cu and all other elements. The SIN normalisation relationship always generated ACL values lower than those generated by the *T aestivum* relationship at soil pH values up to 5.5. At higher soil pH values the situation was reversed. In addition, the ACLs generated by the SIR relationship (based on OC) were lower than all the ACLs generated by the *T. aestivum* relationship except when the OC was set at 1 in the *T. aestivum* relationship. Therefore one set of soil-specific ACLs was generated for *T. aestivum* and another for SIN with the lowest of the two at each pH being adopted as the CEC-pH-based ACL values for Cu.

The pH and CEC based ACLs for Cu were presented in tables in this Schedule. The actual ACL values that apply for Cu are the lowest of either the pH-based ACLs or the CEC-based ACLs, depending on the properties of the soil in question.

13.7 Appendix G. Raw toxicity data for lead

Table G1. The raw toxicity data for lead and the ageing leaching factor that were used in the derivation of the soil quality guidelines derived in this project and the source of the toxicity data.

Species	Endpoint	NOEC or EC10 (added)	LOEC and EC30 (added)	EC50 (added)	ALF	References
Avena sativa	root yield	100	500	300	4.2	Khan and Frankland 1984
Hordeum vulgare	shoot yield	50	250	1270	4.2	Aery & Jagetiya 1984
Lactuca sativa	shoot yield	432	648	2553	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield	1172	1758	107	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield	457	686	960	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield	5120	7680	7500	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield			132	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield			141	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield			240	4.2	Stevens et al, 2003
Lactuca sativa	shoot yield			847	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield			807	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield			731	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield			2290	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield			2630	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield			3090	4.2	Stevens et al. 2003
Lactuca sativa	shoot yield			3100	4.2	Stevens et al. 2003
Lactuca sativa	germination	125	188	174	4.2	Vaughan & Greenslade 1998
Picea rubens	net photosynthesis	141	212	1228	4.2	Seiler & Paganelli 1987
Pinus taeda	root yield	546	819	659	4.2	Seiler & Paganelli 1987
Raphanus sativus	root yield	100	500	1800	4.2	Khan and Frankland 1983

Raphanus sativus	chlorophyll	100	500	300	4.2	Zaman and Zereen 1998
Triticum aestivum	net photosynthesis	1138	1707	5613	4.2	Waegeneers et al. 2004
Triticum aestivum	net photosynthesis	2064	3096	5037	4.2	Waegeneers et al. 2004
Triticum aestivum	net photosynthesis	1614	2421	5200	4.2	Waegeneers et al. 2004
Triticum aestivum	root yield	250	500	750	4.2	Khan and Frankland 1984
Zea mays	root length	100	150	300	4.2	LDA 2008
Dendrobaena rubida	hatching success	129	194	387	4.2	Bengtsson et al. 1986
Eisenia andrei	survival	1000	1500	3410	4.2	Vaughan & Greenslade 1998
Eisenia fetida	reproduction	608	912	1629	4.2	Spurgeon & Hopkin 1995
Eisenia fetida	reproduction	1810	2715	3760	4.2	Spurgeon et al. 1994
Eisenia fetida	reproduction	400	600	1200	4.2	Davies et al. 2003a
Eisenia fetida	reproduction	3000	4500	9000	4.2	Davies et al. 2003b
Folsomia candida	reproduction	2000	5000	1360	4.2	Sandifer & Hopkin 1996
Folsomia candida	reproduction	400	2000	2970	4.2	Sandifer & Hopkin 1996
Folsomia candida	reproduction	2000	3000	3160	4.2	Sandifer & Hopkin 1996
Folsomia candida	reproduction	400	2000	1570	4.2	Sandifer & Hopkin 1997
Folsomia candida	reproduction			2970	4.2	Sandifer & Hopkin 1997
Folsomia candida	reproduction	1300	1950	1900	4.2	Bongers et al. 2004
Folsomia candida	reproduction	1138	1707	3414	4.2	Waegeneers et al. 2004
Folsomia candida	reproduction	2064	3096	6192	4.2	Waegeneers et al. 2004
Folsomia candida	reproduction	1614	2421	4842	4.2	Waegeneers et al. 2004
Folsomia candida	reproduction			2560	4.2	Waegeneers et al. 2004

Lumbriculus rubellus	growth	1000	1500	3000	4.2	Ma, 1982
denitrification		250	500	750	4.2	Bollag & Barabasz 1979
nitrification		448	672	1344	4.2	Waegeneers et al. 2004
nitrification		2064	3096	6192	4.2	Waegeneers et al. 2004
nitrification		253	380	759	4.2	Waegeneers et al. 2004
N-mineralisation		200	300	600	4.2	Chang & Broadbent 1982
N-mineralisation		1000	4000	3000	4.2	Wilke 1989
respiration		188	282	564	4.2	Doelman & Haanstra 1979
respiration		1500	2250	4500	4.2	Doelman & Haanstra 1979
respiration		750	1125	2250	4.2	Doelman & Haanstra 1979
respiration		1000	1500	3000	4.2	Doelman & Haanstra 1984
respiration		150	225	450	4.2	Doelman & Haanstra 1984
respiration		400	600	1200	4.2	Doelman & Haanstra 1984
respiration		93	140	400	4.2	Chang & Broadbent 1981
respiration		100	150	300	4.2	Saviozzi et al. 1997
respiration		4144	6216	12432	4.2	Speir et al. 1999
respiration		2279	3419	6838	4.2	Frostegård et al. 1993
substrate induced respiration		2072	3108	6216	4.2	Speir et al. 1999
substrate induced respiration		1450	2175	4350	4.2	Speir et al. 1999
ATP				3108	4.2	Frostegård et al. 1993

13.8 Appendix H: Raw toxicity data for nickel

Table H1: The raw toxicity data for nickel and the ageing leaching factor that were used in the derivation of the soil quality guidelines derived in this project and the source of the toxicity data.

Species	Endpoint	NOEC & EC10 added (mg/kg)	Collated LOEC & EC30 added (mg/kg)	Collated EC50 added (mg/kg)	ALF	References
Lycopersicon esculentum	shoot yield	21	31.5	63	1.01	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	599	898.5	1797	1.02	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	16	24	48	1.02	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	125	187.5	375	1.02	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	10	15	30	1.03	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	42	63	126	1.07	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	52	78	156	1.14	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	150	225	450	1.28	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	118	177	354	1.66	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	250	375	750	2.00	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	200	300	600	3.32	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	504	756	1512	3.01	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	224	336	672	3.32	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	144	216	432	3.32	Oorts et al. 2006
Lycopersicon esculentum	shoot yield	189	283.5	567	3.66	Oorts et al. 2006
Hordeum vulgare	root yield	31	46.5	93	1.01	Oorts et al. 2006
Hordeum vulgare	root yield	1101	1651.5	3303	1.02	Oorts et al. 2006
Hordeum vulgare	root yield	90	135	270	1.02	Oorts et al. 2006
Hordeum vulgare	root yield	249	373.5	747	1.02	Oorts et al. 2006
Hordeum vulgare	root yield	46	69	138	1.03	Oorts et al. 2006
Hordeum vulgare	root yield	123	184.5	369	1.07	Oorts et al. 2006
Hordeum vulgare	root yield	261	391.5	783	1.14	Oorts et al. 2006
Hordeum vulgare	root yield	128	192	384	1.14	Oorts et al. 2006

Hordeum vulgare	root yield	398	597	1194	1.28	Oorts et al. 2006
Hordeum vulgare	root yield	106	159	318	1.66	Oorts et al. 2006
Hordeum vulgare	root yield	211	316.5	633	2.00	Oorts et al. 2006
Hordeum vulgare	root yield	268	402	804	3.32	Oorts et al. 2006
Hordeum vulgare	root yield	289	433.5	867	3.01	Oorts et al. 2006
Hordeum vulgare	root yield	587	880.5	1761	3.32	Oorts et al. 2006
Hordeum vulgare	root yield	96	144	288	3.32	Oorts et al. 2006
Hordeum vulgare	root yield	304	456	912	3.66	Oorts et al. 2006
Spinach	yield	10	21.7	32.7	1.03	Willaert and Verloo 1988
Spinach	yield	100	40	40	5.66	Willaert and Verloo 1988
Spinach	yield		200	200	5.66	Willaert and Verloo 1988
Avena sativa	grain yield	500	750	1500	2.32	Halstead et al. 1969
Avena sativa	grain yield	20	51	56.2	1.12	Halstead et al. 1969
Avena sativa	grain yield	50	75.7	100	1.12	Halstead et al. 1969
Avena sativa	grain yield	50	55.4	63.1	1.38	Halstead et al. 1969
Avena sativa	grain yield	50	82.2	100	1.33	Halstead et al. 1969
Avena sativa	grain yield	100	144	159	1.08	Halstead et al. 1969
Avena sativa	grain yield	100	144	159	1.07	Halstead et al. 1969
Avena sativa	grain yield	100	144	159	1.43	Halstead et al. 1969
Avena sativa	grain yield	100	144	159	1.28	Halstead et al. 1969
Avena sativa	grain yield	66	99	198	1.14	De Haan et al. 1985
Avena sativa	grain yield	45	67.5	135	1.11	De Haan et al. 1985
Avena sativa	grain yield	47	70.5	141	1.08	De Haan et al. 1985
Avena sativa	grain yield	16	24	48	1.06	De Haan et al. 1985
Avena sativa	grain yield	40	60	120	1.11	De Haan et al. 1985
Avena sativa	yield	80	171	241	3.01	Liang and Schoenau 1995
Avena sativa	yield	>160	160	160	3.01	Liang and Schoenau 1995
Avena sativa	yield					
Medicago sativa	EC10y(t)	100	366	404	3.32	Halstead et al. 1969
Medicago sativa	EC10y(t)	100	389	423	2.32	Halstead et al. 1969
Medicago sativa	EC10y(t)	20	19.1	20.9	1.12	Halstead et al. 1969

Medicago sativa	EC10y(t)	20	47.6	49.9	1.38	Halstead et al. 1969
Medicago sativa	EC10y(t)	20	40.5	42.3	1.33	Halstead et al. 1969
Medicago sativa	EC10y(t)	20	43.5	45.5	1.08	Halstead et al. 1969
Medicago sativa	EC10y(t)	50	101	106	1.07	Halstead et al. 1969
Medicago sativa	EC10y(t)	20	45.6	48.2	1.43	Halstead et al. 1969
Medicago sativa	EC10y(t)	50	100	118	1.28	Halstead et al. 1969
Raphanus sativus	yield	80	100.8	115	3.01	Liang and Schoenau 1995
Raphanus sativus	yield	>160	160	160		Liang and Schoenau 1995
Allium cepa	yield	46	73.1	103.4	7.17	Dang et al. 1990
Trigonella poenumgraceum	yield	84	132.8	176.6	7.17	Dang et al. 1990
Lolium perenne	yield	110	134.8	153.3	1.25	Frossard et al. 1989
Lactuca sativa	leaves yield	13	41	50.1	1.05	Gupta et al. 1987
Lactuca sativa	leaves yield	155	260	316	1.14	Gupta et al. 1987
Lactuca sativa	leaves yield	230	412	501	3.66	Gupta et al. 1987
Lactuca sativa	leaves yield	334	653	794	1.57	Gupta et al. 1987
Lactuca sativa	yield	40	77.5	99.5	3.01	Liang and Schoenau 1995
Zea mays	yield	120	164	200	4.53	Metwally and Rabie 1989
Zea mays	yield	40	107	158	6.37	Metwally and Rabie 1989
Folsomia candida	reproduction	36.4	54.6	109.2	1.01	University of Ghent and Euras 2005
Folsomia candida	reproduction	558	837	1674	1.02	University of Ghent and Euras 2005
Folsomia candida	reproduction	120	180	360	1.02	University of Ghent and Euras 2005
Folsomia candida	reproduction	527	790.5	1581	1.02	University of Ghent and Euras 2005
Folsomia candida	reproduction	104	156	312	1.03	University of Ghent and Euras 2005
Folsomia candida	reproduction	101	151.5	303	1.14	University of Ghent and Euras 2005
Folsomia candida	reproduction	180	270	540	1.14	University of Ghent and Euras 2005
Folsomia candida	reproduction	622	933	1866	1.28	University of Ghent and Euras 2005
Folsomia candida	reproduction	269	403.5	807	1.66	University of Ghent and Euras 2005
Folsomia candida	reproduction	384	576	1152	2.00	University of Ghent and Euras 2005

Folsomia candida	reproduction	662	993	1986	3.32	University of Ghent and Euras 2005
Folsomia candida	reproduction	828	1242	2484	3.01	University of Ghent and Euras 2005
Folsomia candida	reproduction	1100	1650	3300	3.32	University of Ghent and Euras 2005
Folsomia candida	reproduction	61.7	92.55	185.1	3.32	University of Ghent and Euras 2005
Folsomia candida	reproduction	562	843	1686	3.66	University of Ghent and Euras 2005
Folsomia candida	reproduction	320	560	476	1.25	Lock and Janssen 2002
Folsomia candida	mortality		1000	1000	1.25	Lock and Janssen 2002
Folsomia fimetaria	reproduction	173	259.5	519	1.12	Scott-Fordsmand et al. 1998
Eisenia fetida	reproduction	49.8	74.7	149.4	1.01	University of Ghent and Euras 2005
Eisenia fetida	reproduction	1110	1665	3330	1.02	University of Ghent and Euras 2005
Eisenia fetida	reproduction	54.5	81.75	163.5	1.02	University of Ghent and Euras 2005
Eisenia fetida	reproduction	362	543	1086	1.02	University of Ghent and Euras 2005
Eisenia fetida	reproduction	46.5	69.75	139.5	1.03	University of Ghent and Euras 2005
Eisenia fetida	reproduction	182	273	546	1.07	University of Ghent and Euras 2005
Eisenia fetida	reproduction	230	345	690	1.14	University of Ghent and Euras 2005
Eisenia fetida	reproduction	66.1	99.15	198.3	1.14	University of Ghent and Euras 2005
Eisenia fetida	reproduction	151	226.5	453	1.28	University of Ghent and Euras 2005
Eisenia fetida	reproduction	172	258	516	1.66	University of Ghent and Euras 2005
Eisenia fetida	reproduction	297	445.5	891	2.00	University of Ghent and Euras 2005
Eisenia fetida	reproduction	233	349.5	699	3.32	University of Ghent and Euras 2005
Eisenia fetida	reproduction	239	358.5	717	3.01	University of Ghent and Euras 2005
Eisenia fetida	reproduction	490	735	1470	3.32	University of Ghent and Euras 2005
Eisenia fetida	reproduction	186	279	558	3.32	University of Ghent and Euras 2005
Eisenia fetida	reproduction	198	297	594	3.66	University of Ghent and Euras 2005
Eisenia fetida	reproduction	180	320	362	1.25	Lock and Janssen 2002
Eisenia fetida	mortality		1000	1000	1.25	Lock and Janssen 2002
Enchytraeus albidus	reproduction	180	320	275	1.25	Lock and Janssen 2002
Enchytraeus albidus	mortality		127.5	510	1.25	Lock and Janssen 2002

Eisenia veneta	reproduction	85	300	300	1.12	Scott-Fordsmand et al. 1998
Lumbricus rubellus	mortality	842	1080	1190	2.52	Ma, 1982
Microbial process	nitrification	170	255	510	1.02	University of Leuven 2005
Microbial process	nitrification	111	166.5	333	1.02	University of Leuven 2005
Microbial process	nitrification	44	66	132	1.14	University of Leuven 2005
Microbial process	nitrification	137	205.5	411	1.14	University of Leuven 2005
Microbial process	nitrification	67	100.5	201	1.66	University of Leuven 2005
Microbial process	nitrification	214	321	642	2.00	University of Leuven 2005
Microbial process	nitrification	439	658.5	1317	3.01	University of Leuven 2005
Microbial process	nitrification	169	253.5	507	3.32	University of Leuven 2005
Microbial process	nitrification	53	79.5	159	3.32	University of Leuven 2005
Microbial process	nitrification	67	100.5	201	3.66	University of Leuven 2005
Microbial process	N-mineralisation	257	385.5	771	2.00	Smolders 2000
Microbial process	N-mineralisation	20	30	60	2.00	Smolders 2000
Microbial process	Glucose respiration	22	33	66	1.02	
Microbial process	Glucose respiration	254	381	762	1.14	University of Leuven 2005
Microbial process	Glucose respiration	376	564	1128	1.28	University of Leuven 2005
Microbial process	Glucose respiration	45	67.5	135	1.66	University of Leuven 2005
Microbial process	Glucose respiration	242	363	726	2.00	University of Leuven 2005
Microbial process	Glucose respiration	116	174	348	3.32	University of Leuven 2005
Microbial process	Glucose respiration	302	453	906	3.01	University of Leuven 2005
Microbial process	Glucose respiration	167	250.5	501	3.32	University of Leuven 2005
Microbial process	Glucose respiration	140	210	420	3.32	University of Leuven 2005
Microbial process	Glucose respiration	56	84	168	3.66	University of Leuven 2005
Microbial process	MRR	42	63	126	1.01	University of Leuven 2005
Microbial process	MRR	343	514.5	1029	1.02	University of Leuven 2005
Microbial process	MRR	55	82.5	165	1.14	University of Leuven 2005
Microbial process	MRR	121	181.5	363	1.28	University of Leuven 2005
Microbial process	MRR	88	132	264	2.00	University of Leuven 2005
Microbial process	MRR	203	304.5	609	3.01	University of Leuven 2005

Microbial process	MRR	446	669	1338	3.32	University of Leuven 2005
Microbial process	MRR	370	555	1110	3.66	University of Leuven 2005
Aspergillus flavipes	hyphal growth	347	386.9	414.2	1.05	Babich and Stotzky 1982b
Aspergillus flavus	hyphal growth	393	510.2	600.8	1.05	Babich and Stotzky 1982b
Aspergillus clavatus	hyphal growth	13	40	79.3	1.05	Babich and Stotzky 1982b
Aspergillus niger	hyphal growth	400	474.5	527.8	1.05	Babich and Stotzky 1982b
Penicillium vermiculatum	hyphal growth	102	235.9	400.4	1.05	Babich and Stotzky 1982b
Rhizopus stolonifer	hyphal growth	288	352.2	399.8	1.05	Babich and Stotzky 1982b
Trichoderma viride	hyphal growth	530	597.9	644.8	1.05	Babich and Stotzky 1982b
Gliocladium sp.	hyphal growth	200	505	902.4	1.05	Babich and Stotzky 1982b
Serratia marcescens	colony count	155	293.3	344.1	1.05	Babich and Stotzky 1982b
Proteus vulgaris	colony count	15	77.4	216.6	1.05	Babich and Stotzky 1982b
Bacillus cereus	colony count	285	880.4	1706	1.05	Babich and Stotzky 1982b
Nocardia rhodochrous	colony count	177	577.2	821.6	1.05	Babich and Stotzky 1982b
Rhodotorula rubra	colony count	247	729.3	1565	1.05	Babich and Stotzky 1982b
Microbial process	Respiration	400	8000	8000	2.00	Doelman and Haanstra 1984
Microbial process	Respiration		8000	8000	2.00	Doelman and Haanstra 1984
Microbial process	Respiration	2542	8000	8000	1.25	Doelman and Haanstra 1984
Microbial process	Respiration		1370	7292	1.25	Doelman and Haanstra 1984
Microbial process	Respiration	291	8000	8000	3.66	Doelman and Haanstra, 1984
Microbial process	Respiration		8000	8000	3.66	Doelman and Haanstra 1984

Microbial process	Respiration		8000	8000	3.01	Doelman and Haanstra 1984
Microbial process	Respiration		8000	8000	3.01	Doelman and Haanstra 1984
Microbial process	Respiration		3585	12072	1.03	Doelman and Haanstra 1984
Microbial process	Respiration	27	93.9	1655	1.08	Saviozzi et al. 1997
Microbial process	Glutamate respiration	55	400	800	2.00	Haanstra and Doelman 1984
Microbial process	Glutamate respiration	55	400	800	1.03	Haanstra and Doelman 1984
Microbial process	Glutamate respiration	55	400	800	3.01	Haanstra and Doelman 1984
Microbial process	Glutamate respiration		55	110	3.66	Haanstra and Doelman 1984
Enzyme	ATP content	77	115.5	400	1.25	Wilke 1988
Enzyme activity	urease	120	180	410	2.00	Doelman and Haanstra 1986
Enzyme activity	urease				2.00	Doelman and Haanstra 1986
Enzyme activity	urease	2300	3450	2790	1.25	Doelman and Haanstra 1986
Enzyme activity	urease				1.25	Doelman and Haanstra 1986
Enzyme activity	urease	130	195	1740	3.66	Doelman and Haanstra 1986
Enzyme activity	urease				3.66	Doelman and Haanstra 1986
Enzyme activity	urease	90	135	370	3.01	Doelman and Haanstra 1986
Enzyme activity	urease				3.01	Doelman and Haanstra 1986
Enzyme activity	urease	540	810	2320	1.03	Doelman and Haanstra 1986
Enzyme activity	urease				1.03	Doelman and Haanstra 1986
Enzyme activity	phosphatase	7021	10531.5	10071	2.00	Doelman and Haanstra 1989
Enzyme activity	phosphatase	251	376.5	8040	1.25	Doelman and Haanstra 1989
Enzyme activity	phosphatase	380	570	2130	3.66	Doelman and Haanstra 1989
Enzyme activity	phosphatase			6514	3.01	Doelman and Haanstra 1989
Enzyme activity	arylsulfatase	372	558	2119	2.00	Doelman and Haanstra 1991
Enzyme activity	arylsulfatase			98.6	2.00	Doelman and Haanstra 1991
Enzyme activity	arylsulfatase	610	915	2347	1.25	Doelman and Haanstra 1991
Enzyme activity	arylsulfatase	2207	3310.5	5399	3.66	Doelman and Haanstra 1991
Enzyme activity	arylsulfatase			92.1	3.66	Doelman and Haanstra 1991
Enzyme activity	arylsulfatase	272	408	5658	3.01	Doelman and Haanstra 1991
Enzyme activity	arylsulfatase			2436	3.01	Doelman and Haanstra 1991

Enzyme activity	arylsulfatase	7080	10620	8099	1.03	Doelman and Haanstra 1991
Enzyme activity	dehydrogenase	7.9	24.3	100	2.03	Welp 1999
Enzyme activity	saccharase	77	115.5	400	1.25	Wilke 1988
Enzyme activity	protease	77	115.5	400	1.25	Wilke 1988

MRR = maize residue respiration.

13.9 Appendix I: Raw toxicity data for trivalent chromium

Table I1. The raw toxicity data for trivalent chromium and the ageing leaching factor that were used in the derivation of the soil quality guidelines derived in this project and the source of the toxicity data.

Species	Endpoint	NOEC or EC10 added	LOEC or EC30 added	EC50 added	Reference
Agrostis tenuis	growth	3333	5000	10000	Beeze, 1973
Avena sativa	growth	400	600	1200	De Haan et al. 1985
Avena sativa	growth	200	300	600	De Haan et al. 1985
Avena sativa	growth	200	300	600	De Haan et al. 1985
Avena sativa	growth	400	600	1200	De Haan et al. 1985
Avena sativa	growth	200	300	600	De Haan et al. 1985
Avena sativa	growth	800	1200	2400	De Haan et al. 1985
Avena sativa	growth	500	750	1500	McGrath 1982
Beans	growth	200	500	600	Sykes et al. 1981
Brassica juncea	biomass	500	750	1100	Han et al. 2004
Grass	growth	200	500	600	Sykes et al. 1981
Grass	growth				
H. vulgare	growth	200	300	600	Patterson 1971
H. vulgare	growth	200	300	600	Patterson 1971
H. vulgare	growth	200	300	600	Patterson 1971
L. sativa	growth	500	750	1500	Sykes et al. 1981
L. sativa	growth	133	200	400	Sykes et al. 1981
Lollium perenne	growth	3333	5000	10000	Beeze 1973

Phaseoleus vulgaris	growth	50	100	200.0	Wallace et al. 1976
Phaseoleus vulgaris	growth	33.3	50	100	Wallace et al. 1976
R. sativus	growth	500	750	1500	Sykes et al. 1981
R. sativus	growth	133	200	400	Sykes et al. 1981
Secale cereale	growth	233	350	700	Cunningham et al. 1975
Secale cereale	growth	233	350	700	Cunningham et al, 1975
Z. mays	growth	233	350	700	Cunningham et al. 1975
Z. mays	growth	80	320	640	Mortvedt & Giordano 1975
Z. mays	growth	1360	2040	4080	Mortvedt & Giordano 1975
E. andrei	reproduction	167	250	500.0	Molnar et al. 1989
E. andrei	reproduction	32	100	200	Van Gestel et al. 1993
E. andrei	growth	320	1000	2000	Van Gestel et al. 1992
E. andrei	juveniles per adult	32	100	200	Van Gestel et al. 1992
E. andrei	fertility	320	1000	2000	Van Gestel et al. 1992
E. andrei	fecundity	320	1000	2000	Van Gestel et al. 1992
E. fetida	survival	589	883	1767	Sivakumar & Subbhuraam. 2005
E. fetida	survival	552	828	1657	Sivakumar & Subbhuraam. 2005
E. fetida	survival	598	897	1793	Sivakumar & Subbhuraam. 2005
E. fetida	survival	609	914	1828	Sivakumar & Subbhuraam. 2005
E. fetida	survival	619	928	1856	Sivakumar & Subbhuraam. 2005
E. fetida	survival	567	851	1702	Sivakumar & Subbhuraam. 2005
E. fetida	survival	630	946	1891	Sivakumar & Subbhuraam. 2005
E. fetida	survival	549	823	1646	Sivakumar & Subbhuraam. 2005
E. fetida	survival	587	880	1761	Sivakumar & Subbhuraam. 2005
E. fetida	survival	585	878	1756	Sivakumar & Subbhuraam. 2005

microbial process	arylsulfatase	87	130	260	Al-khafaji et al. 1979
microbial process	arylsulfatase	867	1300	2600	Al-khafaji et al. 1979
microbial process	arylsulfatase	37	55	56	Haanstra and Doelman 1991
microbial process	arylsulfatase	37	55	203	Haanstra and Doelman 1991
microbial process	arylsulfatase	55	83	235	Haanstra and Doelman 1991
microbial process	arylsulfatase	37	55	87	Haanstra and Doelman 1991
microbial process	arylsulfatase	1819	2729	2205	Haanstra and Doelman,1991
microbial process	catalase	0.11	0.67	2.08	Stępniewska et al. 2009
microbial process	catalase	0.19	0.95	2.67	Stępniewska et al. 2009
microbial process	catalase	0.18	0.798	2.03	Stępniewska et al. 2009
microbial process	catalase	0.04	0.219	0.644	Stępniewska et al. 2009
microbial process	catalase	0.72	2.33	4.88	Stępniewska et al. 2009
microbial process	catalase	0.43	1.79	4.4	Stępniewska et al. 2009
microbial process	glutamic acid decomposition	55	400	800	Haanstra and Doelman 1984
microbial process	glutamic acid decomposition	55	400	800	Haanstra and Doelman 1984
microbial process	n mineralisation	50	200	500	Skujins et al. 1986
microbial process	n mineralisation	4.28	18.8	47.8	Chang and Broadbent,1982
microbial process	n mineralisation	400	600	1200	Doelman and Haanstra 1983
microbial process	n mineralisation	423	634	1268	Doelman and Haanstra 1983
microbial process	n mineralisation	324	486	972	Doelman and Haanstra 1983
microbial process	n mineralisation	123	184	368	Doelman and Haanstra 1983
microbial process	n mineralisation	8.00	12	24	Doelman and Haanstra 1983
microbial process	n mineralisation	296	444	888	Doelman and Haanstra 1983
microbial process	n mineralisation	431	646	1292	Doelman and Haanstra 1983
microbial process	n mineralisation	1853	2780	5560	Doelman and Haanstra 1983
microbial process	n mineralisation	2823	4234	8468	Doelman and Haanstra 1983
microbial process	n mineralisation	86.7	130	260	Fu and Tabatabai 1989
microbial process	n mineralisation	173	260	520	Liang and Tabatabai 1977
microbial process	nitrogenase	<<50	<<50	<<50	Skujins et al. 1986

microbial process	respiration	50.0	200	500	Skujins et al. 1986
microbial process	respiration	33.3	50	100	Chang and Broadbent 1981
microbial process	respiration	32.1	219	730	Doelman and Haanstra 1984
microbial process	respiration	2099	7514	>8000	Doelman and Haanstra 1984
microbial process	respiration	66.7	100	200	Ross et al. 1981
microbial process	respiration	66.7	100	200	Ross et al. 1981
microbial process	respiration	0.3	5.3	10.6	Stadelmann and Santschi-Fuhriman 1987
microbial process	respiration	21.3	32	64	Stadelmann and Santschi-Fuhriman 1987
microbial process	urease	50	200	1000.0	Skujins et al. 1986
microbial process	urease	0.093	0.25	0.4	Samborska et al. 2004
microbial process	urease	50	75	150	Bremner and Douglas 1971
microbial process	urease	390	585	630	Doelman and Haanstra, 1986
microbial process	urease	890	1335	1110	Doelman and Haanstra 1986
microbial process	urease	350	525	420	Doelman and Haanstra 1986
microbial process	urease	369	554	1360	Doelman and Haanstra 1986
microbial process	urease	173	260	520	Tabatabai 1977
microbial process	urease	26	26	52	Tabatabai 1977

14 Glossary

ACL (EC50) is the added contaminant limit calculated using 50% effect concentration (EC50) toxicity data.

ACL (LOEC & EC30) is the added contaminant limit calculated using lowest observed effect concentration (LOEC) and 30% effect concentration (EC30) toxicity data.

ACL (NOEC & EC10) is the added contaminant limit calculated using no observed effect concentration (NOEC) and 10% effect concentration (EC10) toxicity data.

Adaptation is (1) change in an organism, in response to changing conditions of the environment (specifically chemical), which occurs without any irreversible disruption of the given biological system and without exceeding the normal (homeostatic) capacities of its response, and (2) a process by which an organism stabilises its physiological condition after an environmental change.

Added contaminant limit (ACL) is the added concentration of a contaminant above which further appropriate investigation and evaluation of the impact on ecological values will be required. ACL values are generated in the process of deriving the three sets of SQGs (calculated using NOEC and EC10, LOEC and EC30, and EC50 toxicity data). ACL values denote which toxicity data were used in their derivation by using subscripts. Thus, ACL(NOEC &EC10), ACL(LOEC & EC30) and ACL(EC50) are calculated using NOEC &EC10, LOEC & EC30, and EC50 data respectively.

Adsorption is the adhesion of molecules to surfaces of solids.

Ambient background concentration (ABC) of a contaminant is the soil concentration in a specified locality that is the sum of the naturally occurring background and the contaminant levels that have been introduced from diffuse or non-point sources by general anthropogenic activity not attributed to industrial, commercial, or agricultural activities.

Bioaccumulation factor (BAF) is a partition coefficient for the distribution of a chemical between an organism exposed through all possible routes and an environmental compartment or food.

Bioaccumulation is the net result of the uptake, distribution and elimination of a substance due to all routes of exposure; that is, exposure to air, water, soil/sediment and food.

Bioavailability is the ability of substances to interact with the biological system of an organism. Systemic bioavailability will depend on the chemical or physical reactivity of the substance and its ability to be absorbed through the gastrointestinal tract, respiratory tract or skin. It may be locally bioavailable at all these sites.

Bioconcentration factor (BCF) is a quantitative measure of a chemical's tendency to be taken up from the ambient environment (for example, water for aquatic organisms and soil or soil pore water for soil organisms). The BCF is the ratio of the concentration of the chemical in tissue (or a specific organ) and the concentration in the ambient environment.

Bioconcentration is the net result of the uptake, distribution and elimination of a substance due to exposure in the ambient environment (for example, water for aquatic organisms and soil or soil pore water for soil organisms).

Biological half life is the time needed to reduce the concentration of a test chemical in the environmental compartment or organisms to half the initial concentration, by transport processes, (for example, diffusive elimination), transformation processes (for example, biodegradation or metabolism) or growth.

Biomagnification factor (BMF) is a quantitative measure of a chemical's tendency to be taken up through food.

Biomagnification is the accumulation and transfer of chemicals via the food web due to ingestion, resulting in an increase of the internal concentration in organisms at the succeeding trophic levels.

Chronic is extended or long-term exposure to a stressor, conventionally taken to include at least a tenth of the life-span of a species.

Default conversion factors are numerical values which are used to convert a measure of toxicity to another measure of toxicity (for example, EC50 to a NOEC) when no experimentally determined values are available.

Ecological investigation level (EIL) is the concentration of a contaminant above which further appropriate investigation and evaluation of the impact on ecological values will be required. The EILs are calculated using EC30 or LOEC toxicity data. EILs are the sum of the added contaminant limit (ACL) and the ambient background concentration (ABC) and the level is expressed in terms of total concentration.

ECx is effective concentration; the concentration which affects X% of a test population after a specified exposure time.

Environmental fate is the destiny of a chemical or biological pollutant after release into the natural environment.

Generic soil quality guidelines describes a single concentration-based value that applies to all Australian soils that have a particular land use. These are derived when normalisation relationships are not available. Compare these with soil-specific soil quality guidelines.

Kd (see **water to soil partition coefficient**).

Koc (see **organic carbon-water partition coefficient**).

Kow (see **octanol-water partition coefficient**).

Leach is the dissolving of contaminants in soil and subsequent downward transport to groundwater or surface waterbodies.

Leachate is water that has percolated through a column of soil.

LOEC is the lowest observed effect concentration; the lowest concentration of a material used in a test that has a statistically significant effect on the exposed population of test organisms compared to the control.

NOEC is no observed effect concentration; the highest concentration of a test substance to which organisms are exposed that does not cause any observed and statistically significant adverse effects on the organisms compared to the controls.

Normalisation relationships are empirical, generally linear relationships which can predict the toxicity of a contaminant to an organism using soil physicochemical properties. These are used in the methodology to generate soil-specific soil quality guidelines.

Octanol-water partitioning (Kow) is the ratio of a chemical's solubility in n-octanol and water at equilibrium. This is widely used as a surrogate for the ability of a contaminant to accumulate in organisms and to biomagnify. These are often expressed in the logarithmic form (that is, log Kow). Chemicals with a log Kow value ≥ 4 is considered to have the potential to biomagnify. There is a linear relationship between log Kow and log Koc values. Thus, Kow can also be used to indicate the ability of chemical to leach to groundwater. A log Kow value < 2 indicates a chemical has the potential to leach to groundwater.

Organic carbon-water partition coefficient (Koc) is the ratio of a chemical's solubility in organic carbon and water at equilibrium. This is widely used as a surrogate for the ability of a contaminant to accumulate in soils and conversely to leach to groundwater or to be removed by surface run-off. These are often expressed in the logarithmic form (that is, log Koc). Chemicals with a log Koc < 2.4 were considered to be mobile and therefore have the ability in some soils to leach to groundwater.

Precautionary principle is the general principle by which all that can reasonably be expected is done to prevent unnecessary risks.

Reference site is a relatively unpolluted site used for comparison with polluted sites in environmental monitoring studies or used for the assessment of ambient background concentrations of contaminants.

Soil quality guidelines (SQGs) are any concentration-based limits for contaminants in soils. Ecological investigation levels are a type of SQG.

Soil-specific soil quality guidelines are a suite of concentration-based values, where each value applies to a soil with different physicochemical properties. These values take into account properties of soils that modify the bioavailability and toxicity of contaminants. These can only be derived if normalisation relationships are available. Compare these to generic SQGs).

Speciation is the exact chemical form or contaminant in which an element occurs in a sample.

Statistically significant effects are effects (responses) in the exposed population which are different from those in the controls at a statistical probability level of $p < 0.05$.

Steady state is the non-equilibrium state of a system in which matter flows in and out at equal rates so that all of the components remain at constant concentrations (dynamic equilibrium).

Water to soil partition coefficient (Kd) is the ratio of the concentration of a contaminant in soil pore water to that in the solid phase of soil at equilibrium. The units are L/kg. This contaminant property is affected by physicochemical properties of the contaminant and the soil. This property is usually expressed as a logarithm (that is, log Kd). A chemical with log Kd <3 is considered to have the potential to leach.

15 Shortened forms

ABC	ambient background concentration
ACL	added contaminant limit
AF	assessment factor
ALF	ageing leaching factor
ANZECC	Australia and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
BAF	bioaccumulation factor
BCF	bioconcentration factor
BMF	biomagnification factor
CCME	Canadian Council of Ministers of the Environment
DAF	dilution and attenuation factor
EC	European commission
EC10	10% effect concentration
EC30	30% effect concentration
EC50	50% effect concentration
ECB	European Chemicals Bureau
Eco-SSL	ecological soil screening level
EIL	ecological investigation level
ERA	ecological risk assessment
EQG	environmental quality guideline
GIL	groundwater investigation level
HIL	health-based investigation level
LOEC	lowest observed effect concentration
NBRP	National Biosolids Research Program
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NOEC	no observed effect concentration
OECD	Organisation for Economic Cooperation and Development
SIN	substrate induced nitrification
SIR	substrate induced respiration
SQG	soil quality guideline

SSD	species sensitivity distribution
US EPA	United States Environmental Protection Agency
TRV	toxicity reference value
TV	trigger value
VROM	Ministry of Housing, Spatial Planning, and the Environment (The Netherlands)