Comparison of Soil Guideline Values Used in New Zealand and Their Derivations

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Summary

Project and Client

Soil guideline values currently developed for use in New Zealand, and the bases of their derivation, were reviewed by Landcare Research for Environment Canterbury on behalf of the Regional Waste Officers Forum, over July-October 2006.

Objectives

- To outline all publicly available soil guideline values, and their basis of derivation, developed to assist, or applicable to, the management of contaminated land in New Zealand.
- To derive soil guideline values for selected contaminants using the methodology proposed by the National Environmental Standard Technical Review Group (NESTRG, MfE 2005).

Results and Conclusions

- Twenty-two documents that recommend or develop soil guideline values for the management of contaminated land at either a national or regional level were reviewed.
- The majority of these focus on protection of human health and use a variation of the *Timber Treatment Guidelines* methodology to derive guideline values.
- With the exception of cadmium and mercury, soil guideline values have been derived for all contaminants considered as priority 1 by NESTRG, but the different documents often contain different values for a given contaminant and land-use as a result of differences in methodology. In addition, different parameters for specific contaminants have been used in the various documents.
- This influences the final soil guideline value and highlights the importance of gaining consensus on all parameters used in the derivation of national guideline values.
- Variations largely include the use of different parameter values, primarily for the dermal-exposure and produce-consumption pathways, and differences in the methodology used to estimate plant uptake of contaminants.
- Soil guideline values for three commonly occurring contaminants for which markedly different guideline values have been previously derived (arsenic, copper and benzo(a)pyrene) were derived using the NESTRG methodology and toxicological intakes (tolerable daily intake, slope factor) used in existing industry-based guidelines, and in Cavanagh & Proffitt (2005). The results are shown below.

Table Summary of soil guideline values derived using the NESTRG methodology.

Chemical	Rural residential	Urban residential	High-density residential	Parks/Active recreation	Industrial (unpaved)
Arsenic (C&P)	15	28	140	60	226
Arsenic (TTG)	40	74	365	142	881
Copper	>10 000	>10 000	>10 000	>10 000	>10 000
Benzo(a)pyrene (C&P)	1.8	5.6	49	22	115
Benzo(a)pyrene (PHG)	0.3	0.9	8	3.5	19

- A limited number of documents consider protection of ecological receptors. Documents that derive soil guideline values specifically for use in management of contaminated land use the same general methodology. However, this methodology differs from that used in the *Biosolids Guidelines*, which provides soil limits for land to which biosolids are applied that could also be applied to contaminated land.

Recommendations

- Rederivation of existing soil guideline values using a common methodology and contaminant-specific parameters is required to ensure consistency in derived guideline values.
- Consensus is required on the toxicological intake (tolerable daily intake, slope factor) and other contaminant-specific parameters used in the derivation of soil guideline values. Agreement on the toxicological intake value should be reached with other agencies who use similar values (eg. MoH, MAF and ERMA).
- Consensus on the general methodology, including parameter values, used to derive soil guideline values is required.

1. Introduction

A number of documents currently available in New Zealand recommend or develop soil guideline values[1] for the management of contaminated land at either a national or regional level. However, these documents may contain different soil guideline values for a given contaminant and land use as a result of differences in the derivation methodology. Environment Canterbury, on behalf of the Regional Waste Officers Forum, commissioned Landcare Research to provide a review of soil guideline values currently used in New Zealand, and the bases of their derivation. The work was carried out over July-October 2006.

2. Background

A soil guideline value is the concentration of a contaminant in soil to which people and/or ecological receptors (e.g. worms, plants) that are living on a site can be exposed with an 'acceptable' level of risk to health. Soil guideline values are based on generic exposure scenarios. More specifically, for the protection of human health soil guideline values for the protection of human health are derived by defining some critical receptor (e.g. child of a certain age and weight) and defining a tolerable daily intake for that receptor for the particular contaminant. Then, using assumptions regarding exposure (e.g. duration, exposure pathway), the soil concentrations that would equal the tolerable daily intake for the assumed exposure are calculated.

For ecological receptors, soil guideline values are developed to provide a certain level of protection for terrestrial species (plants, soil invertebrates and wildlife) and soil microbial functions. For urban sites, protection of terrestrial wildlife is likely to be of lesser concern given the generally localised nature of contamination. Such guideline values are considered to be most applicable to land uses where a functioning ecosystem is desirable (e.g. residential land use, parkland). Soil guideline values for the protection of on-site ecological receptors are also used to provide target values for long-term soil quality.

3. Objectives

- To outline all publicly available soil guideline values, and their basis of derivation, developed to assist, or applicable to, the management of contaminated land in New Zealand.

[1] Alternative names, including 'soil acceptance criteria' and 'health investigation levels', are used to refer to soil guideline values in some documents. In this report 'soil guideline value' is used as the general term for soil concentrations developed to provide protection of human health or ecological receptors, but when discussing information from a particular document, the specific terminology of that document is used.

- To derive soil guideline values for selected contaminants using the methodology proposed by the National Environmental Standard Technical Review Group (NESTRG, MfE 2005).

4. Methods

The documents listed below contain soil guideline values intended for use in, or potentially applicable to, the management of contaminated land in New Zealand, and were reviewed for this study. Some documents have been developed for use nationally and others for application at regional or site level. Only those guideline values developed for generic land-uses were included. All documents reviewed were either publicly available or permission was granted by the commissioning party.

National documents

- Health and Environmental Guidelines for Selected Timber Treatment Chemicals (hereafter referred to as the *Timber Treatment Guidelines*) (MfE & MoH 1997)
- Guidelines for Assessing and Managing Contaminated Gasworks Sites in New Zealand (hereafter referred to as the *Gasworks Guidelines*) (MfE 1997)
- Guidelines for Assessing and Managing Petroleum Hydrocarbon Industry Sites in New Zealand (hereafter referred to as the *Petroleum Hydrocarbon Guidelines*) (MfE 1999)
- *Health Investigation Levels for Dioxin Contaminated Soil.* Report for the Ministry for the Environment (Salcor 2003)
- Assessing and Managing Risks Associated with Former Sheep-dip Sites: A guide for local authorities (hereafter referred to as the *Sheep-dip Guidelines*) (MfE 2006)
- *National Environmental Standard for Contaminated Land: Notes of Technical Review Workshop* (MfE 2005)
- Guidelines for the Safe Application of Biosolids to Land in New Zealand (hereafter referred to as the *Biosolids Guidelines*) (NZWWA 2003)
- *Module 2 – Hazardous Waste Guidelines – Landfill Waste Acceptance Criteria and Landfill Classification* (MfE 2004)

Regional documents

Auckland

- *Review of soil acceptance criteria for copper and DDT.* Report prepared for Auckland Regional Council (Cavanagh 2004a).
- *Review of soil acceptance criteria for lead.* Report prepared for Auckland Regional Council (Cavanagh 2004b).
- *Review of soil acceptance criteria for dieldrin.* Report prepared for Auckland Regional Council (Cavanagh 2004c)
- *Review of soil acceptance criteria for arsenic.* Report prepared for Auckland Regional Council (Cavanagh 2005)
- *Development of soil guideline values protective of ecological receptors in the Auckland Region*. Report prepared for Auckland Regional Council (Cavanagh & O'Halloran 2006)
- *Development of soil guideline values protective of ecological receptors in the Auckland Region: Part 2*. Report prepared for Auckland Regional Council (Cavanagh 2006)
- *Recommended criteria* (Auckland City Council 2006)

Bay of Plenty

- *Derivation* of risk-based soil guideline values for selected contaminants associated with former mill waste in Whakatane. Report prepared for Gulf Resource Management (Cavanagh 2003).

Canterbury

- *Soil acceptance criteria for Sandilands residential area*. Report prepared for the Christchurch City Council (Cavanagh & Proffitt 2005)

Hawke's Bay

- *Agrichemical use and residential development*. Report prepared for Hastings District Council (Pattle Delamore Partners (PDP) 2004).

Tasman

- *Derivation of risk-based acceptance criteria for human health and the environment*. Report prepared for Tasman District Council (Egis 2001).

Waikato

- *Old orchard soil sampling – further assessment of Kura Kaupapa and Kohanga Reo. Report prepared for University of Waikato (PDP 2003).*
- *Suggested guidelines for residential soil sub-division in the Waikato Region. Environment Waikato (Kim 2004)*
- *Recommendations of soil acceptance criteria protective of ecological receptors for contaminants associated with disused sheep dip sites. Report prepared for the Waikato* Pesticide Awareness Committee (Cavanagh & Booth 2003).

5. Results

5.1 Overview of general methodology

Protection of human health

Soil guideline values for the protection of human health represent 'acceptable' concentrations to which people (receptors) can be exposed and are used to assess whether a potential human health risk exists on a given site. Measured concentrations of contaminants in the soil can be compared to these guideline values, and if they are exceeded, a potential human health risk exists. Generally, different guideline values will be determined for different land uses, because the activities on the land have a large influence on the potential human exposure and the level of protection required.

Contaminants are generally referred to as being non-carcinogenic or carcinogenic in terms of their effects on human health. Non-carcinogens are considered to manifest toxic effects if exposure exceeds a threshold concentration, and are often referred to as threshold contaminants. For these contaminants, a tolerable daily intake (TDI), also referred to as a reference dose (RfD), is typically established, and is the daily amount that can be taken into the body without any detrimental health effects occurring.

The potency of carcinogens is typically expressed as (1) a slope factor, which is the risk per daily dose, or (2) an index dose, which is analogous to a TDI. The index dose is the dose that is considered to present a minimal human health risk from exposure to soil contaminants. An index dose can be obtained by dividing the acceptable risk level for cancer incidence (1×10^{-5} in New Zealand) by the slope factor.

Carcinogens can be classified as genotoxic or non-genotoxic, depending on their mode of action. Genotoxic carcinogens are those that act by causing damage to genetic materials, and effects are considered to occur at all levels of exposure. These carcinogens are also generally referred to as non-threshold contaminants. In contrast, non-genotoxic carcinogens do not act directly on genetic material and a number of jurisdictions consider that non-genotoxic carcinogens have a threshold above which toxic effects are manifested, and thus are considered as threshold contaminants. This is the approach that has been adopted in New Zealand.

Soil guideline values are derived by using the exposure assumptions specific for a given scenario and critical receptor. They are set so that exposure in these scenarios cannot exceed either the TDI for threshold contaminants or the dose that results in a specified individual excess cancer risk for non-threshold contaminants. Typically the most sensitive toxicological endpoint (threshold or non-threshold) is used to set the final value.

Protection of ecological receptors

Soil guideline values for the protection of on-site ecological receptors are developed to provide a certain level of protection to terrestrial species and soil microbial functions, and if exceeded may prompt further risk assessment. Ecological receptors typically considered are soil microbial processes, soil invertebrates, terrestrial plants and wildlife.

Ecotoxicological data are used to derive these values, and standardised endpoints, typically either the no-observable-effect concentrations (NOECs) or the lowest-observable-effect concentrations (LOECs), are used. The actual methods used to derive guideline values are dependent on the quality and quantity of available data, and typically follow the hierarchy:

- Distribution-based methods
- Assessment-factor methods
- Equilibrium-partitioning methods.

If sufficient data are available, distribution-based methods are used preferentially. These typically use statistical distribution or a ranked distribution with a particular percentile or cut-off point selected as the guideline value that provides a certain level of protection. Where insufficient data are available, assessment factors are used. In this case, the lowest reported toxicity value is divided by an assessment factor, the value of which is dependent on the amount and type of data available. Where no terrestrial toxicity data are available equilibrium-partitioning methods can be used – these convert aquatic toxicity data for use in the terrestrial environment on the basis of partitioning of the contaminant between water and soil.

Several international agencies provide soil screening values, or other similar values, to facilitate protection of terrestrial ecological systems from the impacts of contaminants. However, different countries use different methods and assumptions to derive soil quality criteria, which gives rise to different values for the same contaminants. A more detailed discussion of derivation methodologies is provided in Cavanagh & O'Halloran (2006)

Soil criteria for the protection of ecological receptors are available for a limited number of contaminants in New Zealand. However, they come from a variety of sources and there is no national consensus about derivation methodology or the extent of ecological protection they provide. A variety of approaches have been adopted in industry-based guidelines for the management of contaminated land (MfE 1997, 1999; MfE & MoH 1997), application of biosolids to land (NZWWA 2003), and waste acceptance criteria (MfE 2004).

5.2 Overview of existing soil guideline values

Soil guideline values that have been developed for, or are applicable to, the management of contaminated land in New Zealand, their basis of protection (human health, ecological receptors), and the source documents are summarised in Table 1. In addition, the priority contaminants, and their relative priority, identified by the National Environmental Standard for Contaminated Land Technical Review Group (MfE 2005) are also shown in Table 1. Table 2 provides a summary of the different land uses for which soil guideline values have been proposed in each document, and whether these values are derived or recommended from a review of existing soil guideline values.

Soil guideline values for the protection of human health have been derived in one or more existing New Zealand documents for all contaminants identified as priority 1 with the exception of cadmium and mercury. Soil guideline values for the protection of human health have been considered for fewer of the priority 2 or 3 contaminants.

A brief description of the methodology used in each document is provided in sections 5.3 and 5.4 with a more detailed comparison given in section 5.5. The greatest number of soil guideline values have been developed for arsenic, copper, lead, benzo(a)pyrene and DDT (see section 5.6), with residential land use being the most commonly considered. Some documents review existing national and international values; the methodology used to derive these guideline values is not discussed in further detail. However, these values are tabulated in Appendices 1 and 2 along with their source for further reference.

Table 1 National and regional soil guideline values protective of human health (HH) and the environment (Eco) developed for New Zealand

	Priority[1]	**National**							**Regional**									
Source documents		**TTG**	**GWG**	**PHG**	**SAL**	**SDG**	**Biosolids**	**WAC**	**ARC**	**ARC-eco**	**ACC**	**BoP**	**CCC**	**HDC**	**TDC**	**UW**	**EW**	**W-Eco**
Basis of protection[2]		**HH**	**HH**	**HH**	**HH**	**HH & Eco**	**HH/Eco**	**HH/Eco**	**HH**	**Eco**	**HH**	**HH**	**HH**	**HH**	**HH & Eco**	**HH**	**HH**	**Eco**
Metals																		
Arsenic	1	✓				✓	✓	✓	✓	✓	✓		✓			✓	✓	✓
Cadmium	1						✓	✓		✓								
Copper	1	✓					✓	✓	✓	✓	✓		✓	✓		✓	✓	
Chromium III	1	✓					✓			✓								
Chromium VI	1	✓						✓		✓								
Lead	1						✓	✓	✓	✓	✓					✓		
Mercury	1						✓	✓		✓								
Nickel	2						✓	✓		✓	✓							
Tin	2							✓					✓					
Zinc	2						✓	✓		✓	✓		✓					
Inorganics																		
Boron	1	✓						✓										
Cyanide	2		✓															
Thallium	3																	
Uranium	3																	
Organics																		
Dieldrin	1					✓		✓	✓	✓					✓			✓
DDT	1					✓		✓	✓	✓				✓	✓	✓	✓	✓
Lindane	2					✓												✓
PCP	1	✓										✓						
Dioxins/ furans	1	✓			✓							✓						

	Priority[1]	National							Regional									
Source documents		**TTG**	**GWG**	**PHG**	**SAL**	**SDG**	**Biosolids**	**WAC**	**ARC**	**ARC-eco**	**ACC**	**BoP**	**CCC**	**HDC**	**TDC**	**UW**	**EW**	**W-Eco**
Basis of protection[2]		**HH**	**HH**	**HH**	**HH**	**HH & Eco**	**HH/Eco**	**HH/Eco**	**HH**	**Eco**	**HH**	**HH**	**HH**	**HH**	**HH & Eco**	**HH**	**HH**	**Eco**
PCBs	2																	
Phenol			✓					✓										
Cresol (o,m)			✓															
Hydrocarbons																		
Benzene	1		✓	✓				✓										
Toluene	2		✓	✓				✓										
Ethyl-benzene	2		✓	✓				✓										
Xylenes	2		✓	✓				✓										
TPH	1			✓														
Napthalene	2		✓	✓				✓										
Non-carcinogenic			✓[3]	✓[4]						✓								
Benzo(a)-pyrene	1		✓[5]	✓[5]				✓[6]		✓	✓[5]		✓					

TTG – *Timber Treatment Guidelines*; GWG – *Gasworks Guidelines*; PHG – *Petroleum Hydrocarbon Guidelines*; SAL – Salcor (2001); SDG – *Sheep-dip Guidelines*; Biosolids – *Biosolids Guidelines*; WAC – waste acceptance criteria; ARC – Auckland Regional Council (Cavanagh 2004a–c, 2005a); ARC-Eco – Auckland Regional Council – ecological receptors (Cavanagh 2006; Cavanagh & O'Halloran 2006); ACC – Auckland City Council (2006); BoP – Bay of Plenty (Cavanagh 2003); CCC- Christchurch City Council (Cavanagh & Proffitt 2005); HDC – Hastings District Council (PDP 2004); TDC – Tasman District Council (Egis 2001); UW – University of Waikato (PDP 2003); EW – Environment Waikato (Kim 2004); W-Eco –Waikato – ecological receptors (Cavanagh & Booth 2003);.

[1] Priority ranking shown in MfE (2005); antinomy, vinyl chloride, 1,2-Dichloroethane, 1,1,1-Trichloroethane, Trichlorethane, Tetrachloroethane are also included in MfE (2005) as priority contamininants – no soil guideline values have been derived for these contaminants; [2] HH&Eco– separate guideline values are provided for human health and environmental protection, HH/Eco – guideline values are the lowest of either protection of human health or the environment; [3] Naphthalene, acenapthene, anthracene, fluorene, phenanthrene, pyrene, fluroanthene, acenapthylene; [4] Pyrene; [5] BaP equivalents; [6] Total concentration limit.

Table 2 Exposure scenarios considered in the reviewed documents (Table 1), and basis for recommended soil guideline values

Document[1]	**Scenario (Land-use and/or receptor)**	**Derived or recommended from review of existing guidelines**
National guidelines		
Timber Treatment Guidelines	Agricultural/Horticultural Residential (10%, 50% produce consumption) Industrial – paved, unpaved Sub-surface maintenance workers	Derived
Gasworks Guidelines	Agricultural/Horticultural Standard residential (10% produce consumption) High-density residential Commercial/Industrial Parkland/Recreational Maintenance workers	Derived
Petroleum Hydrocarbon Guidelines	Agricultural/Horticultural Residential (10, 50% produce consumption) Commercial/Industrial Maintenance workers	Derived
Salcor	Residential (10, 50% produce consumption) Industrial Parkland/recreational Maintenance workers	Derived
Biosolids Guidelines	Land to which biosolids are applied (lowest of protection of human health and ecological receptors	Reviewed/Derived
Sheep-dip Guidelines	Lifestyle (50% produce consumption) Residential (10% produce consumption) High-density residential Parks and recreational Commercial/Industrial Ecological receptors	Derived Reviewed
Regional studies		
Auckland Region	Residential (10% produce consumption)	Reviewed/Derived
Auckland Region	Ecological receptors	Derived
Auckland City	Kindergarten	Reviewed
Bay of Plenty	Residential (50% produce consumption)	Derived
Christchurch City	Residential (0, 5, 10, 50% home-grown produce)	Derived
Hastings	Residential	Derived
Tasman	Residential (10, 50%) produce Commercial (maintenance, landfill maintenance workers) Protection of marine sediment Protection of Groundwater	Derived
Environment Waikato	Residential (10% produce consumption)	Reviewed
University of Waikato	Kindergarten /school	Derived

[1] Refer to Table 1 for source documents and description of acronyms.

5.3 National guidelines

Timber Treatment Guidelines

The *Timber Treatment Guidelines* were developed for the management of land contaminated by timber treatment chemicals and include soil acceptance criteria for the common contaminants found at such sites: arsenic, boron, copper, chromium (III and VI), pentachlorophenol, and dioxins/furans. Values developed for arsenic (agricultural and residential 50% produce consumption only) and dioxins/furans (Table 3) are interim values only. For arsenic, the guideline values derived for arsenic for the agricultural and residential (50% produce consumption) were lower than background concentrations in soil; interim values are the upper limit of background concentrations. The values for dioxins are those developed for the Pentachlorophenol Risk Assessment Study (NTG 1992 cited in MfE & MoH 1997) and were deemed interim as it was indicated they would be reviewed as part of the Ministry for the Environment's Organochlorines Programme.

Table 3 Soil acceptance criteria (mg/kg) provided in the *Timber Treatment Guidelines*

Substance	Agricultural	Residential (50% home-grown produce)	Residential (10% home-grown produce)	Industrial (unpaved)	Industrial (paved)
Arsenic	30	30	30	500	650
Boron	3	3	3	NL	NL
Chromium (III)	600	600	600	NL	NL
Chromium (IV)	4	9	25	360	510
Copper	40	80	130	NL	NL
PCP	0.7	1.4	7	570	1000
Dioxins[1]	0.00001	0.0015	0.0015	0.018	0.09-NL[2]

NL – not limiting

[1]Toxic equivalent values

[2]0.021 provides protection of maintenance work

The methodology provided in the *Timber Treatment Guidelines* is modified from that of the US EPA (e.g. US EPA 1996), and is generally considered to best represent current New Zealand policy in relation to the derivation of soil guideline values. Most subsequent values for use in New Zealand have been derived using only slight variations from this methodology. Therefore, in this report the most details are provided on this methodology.

The *Timber Treatment Guidelines* develop soil guideline values for five exposure scenarios (Table 3), with three pathways of exposure considered for each scenario: soil ingestion, inhalation of particulates, and dermal absorption. An additional pathway, consumption of home-grown produce, is considered for the agricultural and residential scenarios. Soil guideline values for the protection of human health are derived by combining the value from each of the four exposure pathways, i.e. taking the inverse of the sum of the inverses of the pathway values (see below). The underlying premise in existing New Zealand industry-based guidelines is that protection of on-site systems is only required to the extent necessary to facilitate use of the land. Practically this has been translated in the *Timber Treatment Guidelines* to mean protection of plant health. The adopted soil guideline value, therefore, is the lowest that achieves protection of human health or plant health.

The equations used to derive soil guideline values for the individual pathways are based on the same generic equation:

Intake = concentration × contact rate × exposure frequency × exposure duration (1) averaging time × body weight

The pathway-specific equations for threshold contaminants are:

Soil ingestion: $$CDI = \frac{Cs \times IR \times CF \times ED \times EF \times MF}{AT \times BW} \quad (2)$$

Produce consumption: $$CDI = \frac{Cp \times IP \times ED \times EF \times Pg}{AT \times BW} \quad (3)$$

Inhalation of particulates: $$CDI = \frac{Cs \times IH \times ED \times EF \times MF \times R}{AT \times BW \times PEF} \quad (4)$$

Dermal absorption: $$CDI = \frac{Cs \times CF \times AR \times AH \times AF \times ED \times EF}{AT \times BW} \quad (5)$$

Where CDI = chronic daily intake (mg/kg-bw/day)
Cs = contaminant concentration in soil (mg/kg)
IR = soil ingestion rate (mg/day)
CF = conversion factor (10^{-6} kg/mg)
ED = exposure duration (years)
EF = exposure frequency (days/year)
MF = matrix factor, typically set to 1
AT = averaging time (ED × 365 – threshold contaminants, 70 × 365 – non-threshold contaminants) days
BW = body weight (kg)
Cp = concentration in produce (mg/kg)
IP = produce ingestion rate
Pg = Proportion of home-grown produce
IH = inhalation rate (m^3/day)
R = proportion retained in lungs
PEF = particle emission factor (m^3/kg)
AR = exposed skin surface area (cm^2)
AH = soil adherence factor (mg/cm^2)
AF = absorption factor

[Note: The equations provided in the *Timber Treatment Guidelines* for the inhalation and dermal exposure pathways are mathematically incorrect[1]. The correct mathematical formats are those shown above (Equations 4 and 5).]

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[1] These equations are shown in the *Timber Treatment Guidelines* as:

Inhalation of dust: $$CDI = \frac{Cs \times IH \times ED \times EF \times MF \times R \times PEF}{AT \times BW}$$

Dermal absorption: $$CDI = \frac{Cs \times AR \times AH \times AF \times ED \times EF}{AT \times BW}$$

For threshold contaminants, the exposure duration is based on the most sensitive receptor – a child, in the case of agricultural and residential scenarios. For non-threshold contaminants, exposure is averaged over childhood and adult exposure, with age-adjusted ingestion/inhalation/exposed skin surface areas (I_{adj}) given by:

$$I_{adj} = \frac{\sum I_i \times ED_i}{BW_i} \tag{6}$$

where I_i = produce ingestion, soil ingestion, inhalation rate or skin surface area for receptor group *i*
ED_i = exposure duration for receptor group *i*
BW_i = body weight for receptor group *i*.

The *Timber Treatment Guidelines* combine the pathway-specific guideline values to give a combined soil guideline value ($SGV_{combined}$) as follows:

$$SGV_{combined} = \frac{1}{\frac{1}{SGV_{soil}} + \frac{1}{SGV_{produce}} + \frac{1}{SGV_{dermal}} + \frac{1}{SGV_{inhal}}} \tag{7}$$

Ingestion of contaminated soil and consumption of home-grown produce are typically the most significant pathways of exposure in the residential scenario, while soil ingestion and dermal exposure (for some contaminants only) are the primary exposure pathways for commercial/industrial scenarios.

Produce-consumption pathway: Deriving soil guideline values for the produce-consumption pathway requires estimation of both amount and type of produce consumed and of plant uptake of contaminants. As such, there are greater opportunities for differences to arise in the methodology used for this pathway. This has resulted in discrepancies between documents regarding some produce parameters, and differences in methodology used to estimate plant uptake of contaminants (Cavanagh & Proffitt 2005). Further, errors have been noted by previous authors (Proffitt 2003; Cavanagh 2004) in the way soil guideline values have been derived for the produce-consumption pathway in the *Timber Treatment Guidelines*.

Briefly, some of the assumptions used to derive soil guideline values in the *Timber Treatment Guidelines* are:

- 100% of produce consumed by residents on agricultural sites is home-grown, 10% and 50% of produce consumed by resident on other sites is home-grown
- Produce consumed is comprised of 29% root vegetables, 31% stem or leafy vegetables and 40% fruit
- Contaminant uptake in roots is assumed to be 5× that in leafy vegetables, and negligible in fruit
- Produce has 80% moisture content.

Exposure via foliar deposition of contaminated soil particles is also considered in the *Timber Treatment Guidelines*, although it is determined to be insignificant for all contaminants.

For inorganic contaminants, plant uptake is estimated by Equation 8 (sourced from ECETOC 1990) and estimates the contaminant concentrations in root vegetables:

$$C_{root} = C_s \times BCF_{root} \quad (8)$$

where C_{root} = concentration of contaminant in plant root (mg/kg produce)
C_s = contaminant concentration in soil (mg/kg)
BCF_{root} = bioconcentration factor (concentration in root/concentration in soil)
given by: ln (Kd) = 3.02 – 0.85 ln(BCF)
where Kd = distribution coefficient (ml/mg).

For organic contaminants, plant uptake is estimated by Equation 9 (sourced from Travis & Arms 1988) and determines a plant bioaccumulation factor on a dry-weight basis in above-ground parts:

$$\log Bv = 1.588 - 5.78 \log Kow \quad (9)$$

where Bv = bioconcentration factor for above-ground parts (mg/kg DW plant to mg/kg soil).

It should be noted that the US EPA (2003) has criticised the Travis & Arms relationship as being based on few data, some of which are at variance from the source documents they cite (Travis & Arms 1988).

As regards the errors that have been identified, the primary methodological error is in the derivation of contaminant soil concentrations from target produce concentrations, allowing for different rates of bioconcentration of contaminants by roots and leafy vegetables, and different consumption rates. Soil concentration was determined according to Equation 10 in the *Timber Treatment Guidelines*; Equation 11 shows the correct formula. (Further details of the reasons for this discrepancy are provided in Appendix 3.)

$$C_s = \frac{C_p \times Pr}{BCF_{root}} + \frac{C_p \times Pl}{BCF_{leafy}} \quad (10)$$

$$C_s = \frac{C_p}{(BCF_{root} \times Pr) + (BCF_{leafy} \times Pl)} \quad (11)$$

where C_s = contaminant concentration in soil (mg/kg)
C_p = concentration in produce (mg/kg)
BCF_{root} = bioconcentration factor for root vegetables
BCF_{leafy} = bioconcentration factor for leafy vegetables
Pr = proportion of root vegetables consumed
Pl = proportion of leafy vegetables consumed.

In addition, the equation used to estimate plant uptake of inorganic contaminants (Equation 8) is stated in the *Timber Treatment Guidelines* as being applicable to root vegetables yet the source document (ECETOC 1990) indicates this equation is applicable to above-ground parts. Further, this equation is based on bioconcentration factors (BCF) (and produce concentration) expressed as dry weight, which in turn requires that the amount of produce consumed is also expressed as dry weight. This does not appear to have been done in the *Timber Treatment Guidelines*.

Gasworks Guidelines

The *Gasworks Guidelines* were developed for the management of contamination associated with gasworks sites and includes soil acceptance criteria for the protection of human health for; phenol, cresol (*o, m*), cyanide (free and complexed), benzene, toluene, ethylbenzene, xylene, carcinogenic polycyclic aromatic hydrocarbons (PAHs) (benzo(a)pyrene equivalents) and non-carcinogenic PAHs (Table 4). Benzo(a)pyrene equivalents are determined by multiplying a specific carcinogenic PAH by a toxic equivalence factor (TEF, Table 5) and summing the 'toxic equivalent' (TEQ) concentrations. Protection of on-site ecological receptors is nominally provided to the extent necessary to facilitate use of the land. However, the *Gasworks Guidelines* also state that insufficient work has been carried out to establish the ecological considerations for gasworks sites but that it is hoped more attention can be focused on that in the future.

Table 4 Soil acceptance criteria (mg/kg) provided in the *Gasworks Guidelines*

Substance	Agricultural / Horticultural	Residential (50% home-grown produce)	Residential (10% home-grown produce)	High-density residential	Parks / Recreational	Commercial / Industrial
Phenol	30	60	300	NA[1]	NA	NA
Cresol (*o,m*)	5	10	50	NA	600	NA
Benzene	1	1	1	2	8	8
Toluene	60	130	200	200	600	600
Ethylbenzene	50	100	500	1000	3300	NA
Xylene	100	150	150	150	500	500
Non-carcinogenic PAHs						
Naphthalene	2	3	17	70	200	200
Acenapthene	90	170	800	NA	NA	NA
Anthracene	800	1700	9000	NA	NA	NA
Fluorene	80	160	800	NA	NA	NA
Phenanthrene	90	180	900	NA	NA	NA
Pyrene	150	300	1500	NA	NA	NA
Fluoranthene	320	650	3200	NA	NA	NA
Acenphthylene	50	100	500	NA	NA	NA
Carcinogenic PAHs						
Benzo(a)pyrene	0.2	0.4	1	7	2.7	10
Total PAH	80	160	800	9000	4700	-
Cyanide (free)	400	400	400	1600	780[2]	NA
Cyanide (complex)	1000	1000	1000	3900	2000[2]	NA

[1]NA denotes that criterion exceeds 10 000 mg/kg.

[2]Includes consideration of maintenance workers

Table 5 Toxic equivalence factors (TEF) applied to individual carcinogenic PAHs, to yield BaP 'equivalents'

Polycyclic aromatic hydrocarbons (PAHs)	TEF
Benzo(a)pyrene	1
Benzo(a)anthracene	0.1
Benzo(b)fluoranthene	0.1
Benzo(k)fluoranthene	0.1
Chrysene	0.01
Dibenzo(anthracene)	1
Indeno(1,2,3-cd)pyrene	0.1

The *Gasworks Guidelines* develop soil guideline values for five exposure scenarios (Table 2) using the same general methodology as that in the *Timber Treatment Guidelines*. However, different exposure scenarios are considered, exposure via inhalation of volatiles (indoor and outdoor) is considered in addition to the exposure pathways discussed above, and the lowest guideline value derived for an individual exposure pathway, as opposed to the combined value from all pathways, is the final soil guideline value.

Only limited information is provided for the derivation of soil guideline values for the volatilisation pathway, notably the provision of soil properties relating to modelling. Reference to the development of guidelines for the oil industry for a wide range of soil types implies the methodology used in the *Petroleum Hydrocarbon Guidelines* may have been used in the *Gasworks Guidelines*. However, this lack of detail precludes a more detailed comparison of the methodology used for this pathway.

Produce-consumption pathway: The same methodology (including the errors) and assumptions used in the *Timber Treatment Guidelines* are used in the *Gasworks Guidelines* to derive soil guideline values for the produce-consumption pathway, with the exception that 50% of the produce consumed are vegetables and all are assumed to be root crops. Plant uptake of contaminants is based on the Travis & Arms model (1988) as described in the previous section.

Petroleum Hydrocarbons Guidelines

The *Petroleum Hydrocarbon Guidelines* were developed for the management of contamination associated with oil industry sites, primarily service stations. These guidelines include soil guideline values for benzene, toluene, ethylbenzene, xylene, carcinogenic PAHs (benzo(a)pyrene equivalents) and non-carcinogenic PAHs (pyrene, naphthalene) for six soil types (Table 6, soil guideline values for sand only shown). Guideline values developed for the protection of human health are considered to protect plant life and livestock in the agricultural context as the contaminants being considered are readily degradable and volatile (MfE 1999). Benzo(a)pyrene equivalents are determined using the same toxic equivalent factors used in the *Gasworks Guidelines* (Table 5). Protection of ecological receptors is also considered, to facilitate the use of the land, although it is considered that 'given the nature of the contaminants (i.e volatile, readily degradable)…criteria protective of human health are expected to be generally protective of these considerations'.

Table 6 Soil acceptance criteria (mg/kg) provided for sand and surface (<1 m) contamination in the *Petroleum Hydrocarbon Guidelines*

Substance	Agricultural / Horticultural	Residential (10% home-grown produce)[1]	Commercial / Industrial	Maintenance	Groundwater
TPH C_7-C_9	120	120	120	120	NA
TPH C_{10}-C_{14}	58	(470)[2]	(1500)	6500	NA
TPH C_{15}-C_{36}	(4000)	NA[3]	NA	NA	NA
Benzene	1.1	1.1	3.0	3.0	0.17
Toluene	(68)	(68)	(94)	94	(39)
Ethylbenzene	(53)	(53)	(180)	670	(50)
Xylenes	(48)	(48)	(150)	150	(24)
Naphthalene	7.2	58	(190)	640	1.9
Non-carcinogenic (Pyrene)	(160)	(1600)	NA	NA	(56)
Benzo(a)pyrene (eq)	0.027	0.27	(11)	25	(40)

[1]Route-specific values only shown for consumption of 50% home-grown produce
[2] Brackets denote values likely to correspond to formation of residual separate phase hydrocarbons
[3]NA indicates a concentration at which residual separate-phase hydrocarbon is expected to form. For TPH only the estimated criterion exceeds 20 000 mg/kg.

The *Petroleum Hydrocarbon Guidelines* develop soil guideline values for five exposure scenarios (Table 2) using the general methodology provided in the *Timber Treatment Guidelines*. As with the *Gasworks Guidelines,* inhalation of volatiles (indoor and outdoor) is also considered – although in this case volatiles from both soil *and* contaminated groundwater are considered – and the final soil guideline values are based on the lowest derived from all pathways of exposure. Soil guideline values are derived for six soil types and three depths of contamination. However, the soil type primarily influences the values derived for the inhalation pathway for volatile substances, and where the inhalation pathway is not the primary route of exposure, the adopted guideline will be the same regardless of soil type. Further, these guidelines provide soil guideline values for the protection of groundwater for drinking water purposes.

Produce-consumption pathway: The methodology used to derive the soil guideline values for the produce-consumption pathways differs from that used in the *Timber Treatment Guidelines*. Notably, the equation for determining soil concentrations from produce concentration is correct (MfE 1999, appendix 4F), and the model of Ryan et al. (1988) is used to estimate plant uptake of contaminants. This model determines a fresh-weight plant uptake factor for roots and stems from contaminant concentrations in pore water. However, the *Petroleum Hydrocarbon Guidelines* do not indicate the relationship between pore water concentrations and soil concentrations, which become the soil acceptance criteria. The *Petroleum Hydrocarbon Guidelines* also assume a different composition of root and leafy vegetables to that in the *Timber Treatment Guidelines,* notably 10% are assumed to be root vegetables, 50% leafy (stem) vegetables or fruit, and 40% tree-fruits, where tree-fruits are assumed not to uptake contaminants. Finally, generic soil acceptance criteria are only provided for consumption of 10% home-grown produce, while route-specific values for consumption of 50% home-grown produce are provided separately.

Salcor report

The Ministry for the Environment commissioned Salcor (2003) to update the soil acceptance criteria provided in the *Timber Treatment Guidelines* to reflect a change in the dioxin toxicological value upon which the guideline values were based. The original criteria were based on an acceptable daily intake of 10 pg TEQ/kg bw/day, whereas the Ministry for Health endorsed an 'interim maximum monthly intake of 30 pg TEQ/kg bw/day in 2003. Salcor (2003) used the general methodology provided in the *Timber Treatment Guidelines*, and also considered a parkland and recreational exposure scenario, based on the *Gasworks Guidelines*. The agricultural value provided in the *Timber Treatment Guidelines* was not reviewed as it had been adopted directly from the interim Canadian environmental quality criteria (Salcor 2003). The derived soil guideline values are shown in Table 7. This document has no official government status.

Table 7 Health investigation levels (mg/kg) provided in Salcor (2003)

Substance	Residential	Parkland / Recreational	Industrial (unpaved)	Industrial (paved)	Maintenance
Dioxin TEQ	0.000063	0.00012	0.00074	0.0037 to unlimiting	0.0015

Sheep-dip Guidelines

The Ministry for the Environment recently released a draft of the *Sheep-dip Guidelines* for consultation (MfE 2006). This is the most recent national guidance document to include soil guideline values for the management of contaminated land. It includes derivation of soil guideline values for the protection of human health for DDTs, dieldrin and lindane (Table 8). Soil guideline values are also provided for arsenic although these are adopted from the *Timber Treatment Guidelines*. This document summarises soil guideline values for sheep-dip chemicals developed in New Zealand for the protection of ecological receptors.

The *Sheep-dip Guidelines* derive soil guideline values for five exposure scenarios (Table 2) using a corrected and updated version of the methodology provided in the *Timber Treatment Guidelines* and exposure scenarios largely based on those provided in the *Gasworks Guidelines*.

Table 8 Soil guideline values (mg/kg) provided in the *Sheep-dip Guidelines*

Substance	Lifestyle block[1]	Standard residential	High-density urban residential[2]	Parks / Recreation	Commercial / Industrial (unpaved)
Arsenic[3]	30	30	100	-[4]	500
∑DDTs[5]	8.4	28	70	140	1700
Dieldrin	0.7	2.7	12	23	190
Lindane	33	140	700	1400	14,000

[1] The consumption of products (eggs, milk, meat) from animals raised on site is excluded and should be considered on a site-specific basis.
[2] Based on residential value with no produce consumption.
[3] Values provided in *Timber Treatment Guidelines* (MfE & MoH 1997).
[4] No value derived for this land use in New Zealand; refer to international guidelines (e.g. NEPC 1999 or CCME 2003).
[5] Sum of all DDT and DDT metabolites (DDD and DDE).

NESTRG recommendations

During 2005, a technical review group (TRG) was convened to assist in the development of a national environmental standard for contaminated land (NES). As part of these discussions, a methodology for the derivation of soil guideline values for the protection of human health was agreed for a range of exposure scenarios. This was largely based on the methodology and scenarios proposed by Cavanagh (2005b), which in turn were based on a corrected and updated version of the *Timber Treatment Guideline* methodology for five exposure scenarios (Table 2). The key difference between the final agreed methodology and that used previously in New Zealand is that for exposure scenarios including children (residential, parks and recreational) the exposure duration for threshold contaminants is based on the exposure of children and adults (6+24 years), as opposed to children only (6 years) (MfE 2005).

Biosolids Guidelines and waste acceptance criteria

The *Biosolids Guidelines* and waste acceptance criteria were not primarily developed to assist in the management of contaminated land although they could be applied to contaminated land (*Biosolids Guidelines*) or may impact on the disposal of contaminated soil (waste acceptance criteria).

The *Biosolids Guidelines* were developed to provide guidance on the application of biosolids to land. They include soil limits (which represent the maximum permissible concentrations in the receiving environment) for a range of metal and metalloid contaminants (Table 9). These limits are an update of soil limits proposed by the Department of Health (1992) and are generally based on the lowest concentration that provides protection for human health or ecological receptors. In some cases, the soil limit was set for consistency with international biosolids limits (mercury) or for minimising residues in plant crops (cadmium). Soil limits for protection of ecological receptors is based on the lowest observed adverse effect concentrations (LOAEC) determined from review of the available literature. The LOAEC approach was deemed to be appropriate by the authors given the effects-based approach of the Resource Management Act 1991 (NZWWA 2003). The lead soil limit is the only one based on protection of human health – this was derived using the *Timber Treatment Guidelines* methodology.

Table 9 Soil limits (mg/kg) specified in the *Biosolids Guidelines*

Substance	Soil limit
Arsenic	20
Cadmium	1
Copper	100
Chromium (Total)[1]	600
Lead	300[2]
Mercury	1
Nickel	60
Zinc	300

[1]Based on the assumption that most chromium in the soil will be present as chromium III.
[2]Based on protection of human health.

The waste acceptance criteria (MfE 2004) are based on leaching of contaminants from landfills to groundwater. They provide for protection of the most sensitive receptor (i.e. humans or the aquatic environment) at a compliance point 100 m downstream of the landfill edge. ‘Leachability limits’ are derived by back-calculation from the desired water quality at the compliance point, by taking into account the amount estimated to be leached through the landfill liner, and dilution and attenuation during horizontal movement of the groundwater (MfE 2004). The groundwater is assumed to be directly below the landfill. The leachability limits are the maximum concentration of the contaminant in leachate from the waste. A screening criteria, which is 20 times the leachability limit, is used to screen solid waste to ascertain whether leachability testing is required. For selected contaminants ‘total concentration limits are set’, which are nominally based on the concentration at which free product will be present in leachate. Waste acceptance criteria are available for Class A or B landfills (Table 10), with values for Class B landfills being 10-fold lower than those for Class

A landfills. However, these criteria may sometimes be lower than soil guideline values used in the management of contaminated land and may result in restrictions to the disposal of contaminated soil to landfill.

Table 10 Screening criteria (mg/kg) and total concentration limits (mg/kg) for selected contaminants specified for Class A and B landfills (MfE 2004)

Substance	Class A	Class B
Arsenic	100	10
Cadmium	20	2
Copper	100	10
Chromium VI	100	10
Lead	100	10
Mercury	4	0.4
Nickel	200	20
Zinc	200	20
Boron	400	40
Dieldrin	8	0.8
DDT[1]	500	50
Phenol	800	80
Benzene	10	1
Toluene	2000	200
Ethylbenzene	1000	100
Xylenes	2000	200
Naphthalene	200	20
Benzo(a)pyrene[1]	300	30

[1] Total concentration limit

5.4 Regional work

Auckland

Protection of human health: Auckland Regional Council commissioned Landcare Research to review available soil guideline values for arsenic, copper, DDT, lead and dieldrin for residential land use (assuming 10% produce consumption) (Cavanagh 2004a,b,c, 2005). With the exception of dieldrin, the recommended soil guideline values were based on review of existing soil guideline values available for use in New Zealand. This included review of guideline values for copper and DDT proposed by Environment Waikato (Kim 2004 discussed below) and Pattle Delamore Partners (PDP 2003, 2004 discussed below); and review of lead guideline values developed in the United States (US EPA1994a,b; US HUD 1995), United Kingdom (UK DEFRA & EA 2002) and in the *Biosolids Guidelines* and MoH (1998). The *Timber Treatment Guidelines* value for arsenic was reviewed in light of the known errors in the produce-consumption pathway, and also that derived by Cavanagh & Proffitt (2005, see below). For dieldrin, the methodology used was based on an updated and revised version of the methodology provided in the *Timber Treatment Guidelines.* The revision was in the calculation of the uptake of contaminants by produce. Specifically, a single bioaccumulation factor was used to estimate uptake of contaminants for all produce consumed and the bioaccumulation factor was based on measured values of bioaccumulation reported in the literature. These guideline values currently have no official status with the Auckland Regional Council.

In addition, Tonkin & Taylor in 2006 developed some interim values for use by Auckland City Council in assessing kindergarten and pre-school sites (Auckland City Council 2006). A series of soil guideline values based on review of existing values were proposed; these values are shown in Table 11, and their source is given in Appendix 1. Further to this work, guideline values were derived for arsenic, copper, lead and benzo(a)pyrene to account for exposures typically occurring at kindergarten and pre-school sites, including pica and non-pica children and exposure to surface soil and soil beneath a barrier mat (Tonkin & Taylor 2006). The values for a non-pica child exposed to surface soil are shown in Table 11. The values for lead were derived using the Leadspread model (California Department of Toxic Substances Control), which relates blood lead levels to exposure from soil; as such the derivation of these values is not discussed in further detail in this report.

Table 11 Soil guideline values (mg/kg) developed for the Auckland Region

Substance	ARC	ACC		
	Residential (10%)	Residential (10%)	Parks and Recreational	Kindergarten (surface soil)
Arsenic	30(9)	30	200	76
Cadmium	-	20	40	-
Chromium (III)	-	600	24 000	-
Copper	370	370[1]	2000	12 700
Lead	300	300	600	460
Nickel	-	600	600	-
Mercury	-	15	30	-
Zinc	-	7000[1]	14 000	-
∑DDTs	25	25	400	-
Aldrin	-	10	20	-
Dieldrin	6	6	20	-
Lindane	-	0.44	-	-
Heptachlor	-	10	20	-
Chlordane	-	50	100	-
Benzo[a]anthracene	-	0.62	-	-
Benzo[b]fluoranthene	-	0.62	-	-
Naphthalene	-	3	> 40	-
Dibenzo[a,h]anthracene	-	0.06	-	-
Indeno[1,2,3-c,d]pyrene	-	0.62	-	-
Benzo(a)pyrene (equivalence)	-	0.27	2	4.6
Total polycyclic aromatic hydrocarbons	-	20	40	-
PCBs	-	0.22	20	-

[1] Under review

Ecological receptors: Auckland Regional Council also commissioned Landcare Research, to develop soil guideline values for the protection of on-site and off-site ecological receptors (Cavanagh 2006; Cavanagh & O'Halloran 2006). Soil guideline values for the protection of on-site ecological receptors were developed for a suite of contaminants (Table 12), but soil guideline values for the protection of off-site ecological receptors was deemed to be too dependent on site-specific considerations to warrant development of meaningful generic values. Cavanagh & O'Halloran (2006) and Cavanagh (2006) provide minimal-risk and serious-risk concentrations, which are based on the nominal protection of 95% and 50% of species respectively. The method used to derive these values was dependent on data availability, with statistical extrapolation used where sufficient data were available and uncertainty factors if not. The uncertainty factors used were those presented in the European Commission Technical Guidance (European Commission 2001), and updates those used by Cavanagh & Booth (2003, below). In some cases the derived soil guideline values were below background, in which case the highest reported background concentration for non-volcanic soils (ARC 2001) was adopted. These guideline values currently have no official status with the Auckland Regional Council.

Table 12 Soil guideline values (mg/kg) developed for the protection of ecological receptors in the Auckland Region.

Substance	Minimal-risk	Serious-risk
Arsenic	12	22
Cadmium	1	12
Chromium	55	68
Chromium (VI)	0.007	20
Copper	45	135
Lead	60	100
Nickel	35	110
Mercury	0.7	65
Zinc	180	200
Phenol	0.8	80
∑DDTs	1.8	13
Dieldrin	0.002	0.5
Pentachlorophenol	0.7	7.1
Benzo(a)pyrene	10	>1000
Naphthalene	0.2	18

Bay of Plenty

Cavanagh (2003) derived soil guideline values for pentachlorophenol, tetrachlorophenol, and hept- and octa-chlorodibenzo-p-dioxins (Hp-CDD, OCDD) for residential land use on both a generic and site-specific basis (Table 13). An updated and revised version of the *Timber Treatment Guidelines* methodology was used, and contaminant-specific parameters were reviewed.

Table 13 Soil guideline values (mg/kg) provided in Cavanagh (2003)

Substance	Residential (10% home-grown produce)	Residential (excluding produce)
Pentachlorophenol	0.64	55
Tetrachlorophenol	17	324
Hp-CDD, OCDD	0.000074[1]	0.000074

[1] Uptake by plants considered to be negligible.

Christchurch City Council

In 2005 Christchurch City Council commissioned Landcare Research to derive soil guideline values for the protection of human health at the Sandilands residential area for selected contaminants of concern. Cavanagh & Proffitt (2005) derived guideline values for arsenic, benzo(a)pyrene, and copper (Table 14), using a revised and updated version of the *Timber Treatment Guidelines* methodology. Contaminant-specific parameters were also reviewed.

Table 14 Soil guideline values (mg/kg) provided in Cavanagh & Proffitt (2005)

Substance	Residential (50% home-grown produce)	Residential (10% home-grown produce)	Residential (5% home-grown produce)	Residential (excluding produce)
Arsenic	9	9	9	9
Copper	>10 000	>10 000	>10 000	>10 000
Lead (100% BA)	130	270	320	390
Lead (60% BA)	210	460	530	650
Benxo(a)pyrene	2	6	8	13

BA = bioavailable.

Hastings District Council

Pattle Delamore Partners (2004) derived soil acceptance criteria for DDT and copper for protection of human health for residential land use for the Hastings District Council, based on a corrected and updated version of the methodology provided in the *Timber Treatment Guidelines* (Table 15). These derivations are also discussed in Proffitt (2003).

Table 15 Soil acceptance criteria (mg/kg) provided in PDP (2004)

Substance	Residential (100% home-grown produce)	Residential (50% home-grown produce)	Residential (10% home-grown produce)	Residential (excluding produce)
DDT	-	8	25	50
Copper	240	500	2300	31300

Tasman District Council

Egis (2001) derived soil guideline values for the protection of human health for dieldrin and DDT for use on the former Fruitgrowers' site in Mapua, for the Tasman District Council (Table 16). The methodology used was similar to that provided in the *Timber Treatment Guidelines* although exposure via consumption of home-grown poultry was also considered for the residential-land-use scenario.

Table 16 Soil acceptance criteria (mg/kg) provided in Egis (2001)[1]

Substance	Residential (50% home-grown produce)	Residential (10% home-grown produce)	Maintenance worker	Landfill operator	Protection of sediments	Protection of groundwater
∑DDTs	110	190	330	650	5	200
Dieldrin	3	5	63	13	3	60

[1] Sediment protection criteria (0.01 mg/kg) and house dust (1100 mg/kg) also provided.

Waikato

University of Waikato: Pattle Delamore Partners (2003) derived soil guideline values for protection of human health for copper, arsenic, and DDT based on exposure of children attending the Kohanga Reo and Kura Kaupapa at the University of Waikato (Table 17). The *Timber Treatment Guidelines* methodology, modified to include appropriate exposure parameters, was used. Produce consumption was not included, and contaminant-specific parameters were also reviewed. A guideline value for lead, based on that used in residential play situations in the United States (US EPA 2001), was also provided.

Table 17 Soil acceptance criteria provided in PDP (2003)

Substance	Site-specific	Residential (10% home-grown produce)[1]	Residential (excluding produce)[2]
Arsenic	105	30	95
Copper	>10 000	130	7800
Lead	400/1200[3]	-	-
DDT	47	-	-

[1] Values provided in the *Timber Treatment Guidelines.*

[2] Derived from data provided in the *Timber Treatment Guidelines*.

[3] Indicated to be based on US EPA (2001) residential play/other areas.

Environment Waikato: Kim (2004, Appendix 2) reviewed soil guideline values from existing New Zealand and international literature and provided recommendations on those to be used, depending on whether protection of human health or ecological receptors was desired. The contaminants considered were arsenic, copper, chromium, lead, mercury, nickel, zinc, and DDT (Table 18). No new guideline values were derived per se so the methodology used to derive each guideline value is not discussed here. Values are tabulated in Appendix 2, which lists the source and justification for selection of the soil acceptance criteria. The value selected for protection of human health for DDT was reviewed by Cavanagh (2004a).

Table 18 Summary of available guideline values and proposed guideline values (mg/kg) for use provided in Kim (2004)

Substance	Human health	Protection of ecological receptors (usually, plants)	Joint human/ecological	Suggested default guideline to use
Arsenic	30	20, 10–20	-	30
Cadmium	1	1	-	1
Chromium	18 000	600	-	600
Copper	370	100; 130	-	370
Lead	280; 400	-	70	300
Mercury	8	1	6.6	1
Nickel	50	60	50	50
Zinc	23 000	300	200	300
DDT	7.9; 17.2	-	0.7	7.9

Waikato Pesticides Awareness Committee – protection of ecological receptors: In 2003, the Waikato Pesticides Awareness Committee (WAIPAC) commissioned soil guideline values for selected sheep-dip chemicals, for the protection of ecological receptors (Cavanagh & Booth 2003). It was intended these values would be presented in a national guidance document on the management of sheep-dip sites. This report provided minimal-risk and serious-risk concentrations, which nominally protect 95% and 50% of species respectively, for arsenic, dieldrin, lindane, and DDTs (Table 19). These guideline values nominally provided protection for soil invertebrates, plants and microbial processes. Protection of terrestrial vertebrates was not included due to their likely transient exposure to sheep-dip contaminants. Arsenic values were based on a review of available soil guideline values. For the remaining contaminants, for which limited data were available, uncertainty factors based on those provided in SNIFFER (2001) were applied to appropriate data. This methodology was subsequently updated by Cavanagh & O'Halloran (2006).

Table 19 Soil acceptance criteria provided in Cavanagh & Booth (2003)

Substance	Minimal-risk	Serious-risk
Arsenic[3]	20	37
∑DDTs[5]	0.043	0.65
Dieldrin	0.007	0.12
Lindane	0.006	2.1

5.5 Comparison of methodologies

As noted above, most documents have used a version of the *Timber Treatment Guidelines* methodology to derive soil guideline values for the protection of human health. The primary difference is that different values were used for selected parameters. Most documents derive soil guideline values for a residential-land-use scenario (see Table 20 for the parameters used for this and the kindergarten/school exposure scenario). Tables 21–24 provide the parameters used in the relevant documents for other land uses.

Residential land use

Many of the parameters used for the residential exposure scenario are the same (Table 20). The kindergarten/school exposure scenario is included in the residential scenario for discussion, as a residential exposure scenario is often used in lieu of a specific kindergarten/schools scenario. In general, produce consumption is not considered in high-density residential scenarios, and an altered exposure frequency is used for the kindergarten/school exposure scenario. Aside from this the general exposure parameters (exposure duration, frequency, averaging time, body weights) are largely identical for all studies. The exceptions in use of the general exposure parameters are Cavanagh (2003), the NESTRG methodology (MfE 2005), PDP (2003) and Tonkin & Taylor (2006). Cavanagh (2003) assumed a lifetime of exposure (70 years) for all contaminants. MfE (2005) assumed an exposure of 30 years for all contaminants and an adult body weight of 75 kg, which is based on the average weight of an adult in the 1997 National Nutrition Survey (Russell et al. 1999). PDP (2003) and Tonkin & Taylor (2006) altered the exposure frequency for the kindergarten/school exposure scenarios. With the exception of the *Gasworks Guidelines* and the *Petroleum Hydrocarbon Guidelines,* studies have typically allocated a variable proportion of the TDI to exposure from soil. How this proportion is decided is discussed under Background exposure (below), and further differences between the methodologies are discussed for each exposure pathway.

Table 20 Parameters used in the derivation of numeric values for threshold and non-threshold contaminants for the residential and kindergarten exposure scenarios*

Source documents	TTG	GWG		PHG	SAL	SD		ARC	ACC	BoP	CCC	HDC	TDC	UW	NEST RG	
Land-use name	Res	Res	HD	Res	Res	Res	HD	Res	K/S	Res	Res	Res	Res	K/S	Res	HD
Exposure frequency (d/yr)	350	350	350	350	350	350	350	350	200	350	350	350	350	250	350	350
Exposure duration – threshold (yr)	6	6	6	6	6	6	6	6	5	70[1]	6	6	6	12	30[1]	30[1]
Exposure duration – non-threshold (yr)	30[1]	30[1]	30[1]	30[1]	30[1]	30[1]	30[1]	30[1]	5	70[1]	30[1]	30[1]	30[1]	12	30[1]	30[1]
Averaging time – non-threshold[2] (yr)	70	70	70	70	-	70	70	70	70	70	70	70	70	70	70	70
Body weight – child (kg)	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15	15
– adult (kg)	70	70	70	70	-	70	70	70	-	70	70	70	70	-	75	75
Percentage of TDI allocated to soil	Var	100	100	100	Var	Var	Var	Var	-	Var	Var	Var	Var	Var	Var	Var
Ingestion pathway																
Soil ingestion rate – child (mg/d)	100	100	20	100	100	100	100	100	100/200	100	100	100	100	100	100	20
– adult (mg/d)	25	25	5	25	NA	25	25	25	-	25	25	25	25	-	25	5
Produce ingested[3] – child (kg/d)	0.13	0.13	-	0.13	0.13	0.077	-	0.13	-	0.077	0.077	0.13	0.13	-	0.077	-
– adult (kg/d)	0.45	0.45	-	0.45	NA	0.254	-	0.45	-	0.254	0.254	0.45	0.45	-	0.254	-
– proportion[4] (%)	10/50	10/50	-	10/50	10	10/50	-	10	-	50	0/5/10/50	10	10/50	-	10/50	-
Dermal pathway																
Exposure duration (hr)	24	24	24	24	24	12	12	24	24	8	8	24	24	24	12	12
Surface area – child (cm^2)	2625	2625	2625	2625	2625	2625	2625	2625	2625	2800	2625	2625	2625	2625	1700	1700
– adult (cm^2)	4700	4700	4700	4700	NA	4700	4700	4700	-	5700	4700	4700	4700	-	5000	5000
Soil adherence factor – child (mg/cm^2)	0.5	0.5	0.1	0.5	0.5	0.2	0.2	0.5	0.5	0.2	0.2	0.5	0.5	0.5	0.2	0.2
– adults (mg/cm^2)	0.5	0.5	0.1	0.5	0.5	0.07	0.07	0.5	-	0.07	0.07	0.5	0.5	-	0.07	0.07
Skin absorption factor	CS	NS	CS	CS	CS	CS	CS	CS	CS	CS	CS	CS		CS	CS	CS
Inhalation pathway																

Source documents	TTG	GWG		PHG	SAL	SD		ARC	ACC	BoP	CCC	HDC	TDC	UW	NEST RG	
Inhalation rate – child (m^3/d)	3.8	3.8	3.8	3.8	3.8	-	-	3.8	-	-	-	3.8	-	3.8	-	-
– adult indoor (m^3/d)	15	15	15	15	-	-	-	15	-	-	-	15	-	-	-	-
– adult outdoor (m^3/d)	20	20	20	20		-	-	20	-	-	-	20	-	-	-	-
Particulate concentration (µg/m^3)	26[5]	-	-	-	26[5]	-	-	26[5]	-	-	-	26[5]	-	26[5]	-	-
Additional factors	0.75[6]	-	-	-	0.75[6]	-	-	0.75[6]	-	-	-	0.75[6]	-	0.75[6]	-	-

[*] Refer to Table 1 for source documents and acronyms. NESTRG – National Environmental Standard Technical Reference Group – MfE (2005).

- = Not applicable; Var = Variable; NS = Not specified; CS = Contaminant specific, Res – Residential; HD – high-density residential; K/S – Kindergarten/school.

[1] Includes 6 yrs as a child; [2] Averaging time for threshold contaminants is the same as the exposure duration; [3] Fresh weight; [4] Proportion grown/sourced on-site; [5] This is used to derive a particle emission factor of 1.9 x 10^8 m^3/kg, which is used to estimate inhalation exposures; [6] Proportion retained in lungs assuming 20% dust arises from contaminated soil.

Background exposure

Exposure to non-threshold contaminants is based on an agreed acceptable increase in risk in cancer incidence, and therefore exposure should be limited as much as is reasonably practicable. It is assumed that exposure from other sources (food, air, water) is also similarly controlled by the same principle. Therefore, background exposure is not taken into account for non-threshold contaminants.

For threshold contaminants, variable approaches have been used in the different documents to take background exposure into account in the derivation of guideline values. In Cavanagh & Proffitt (2005) the background exposure from dietary (including water) intake was estimated and where it was less than 80% of the TDI, 100% of the residual amount is allocated to exposure from soil. Where the estimated background exposure is more than 80% of the TDI, 20% of the TDI is allocated to exposure from soil. This is the approach adopted in the United Kingdom (UK DEFRA & EA 2002). While this approach may seem counter-intuitive, it recognises that generic soil guideline values are inherently conservative and provides a pragmatic approach to deriving soil guideline values for contaminants for which the estimated background exposure is close to the relevant TDI. For example, where contaminants for which the estimated dietary intake is at or above the selected TDI, and where the contaminant is not detected in most foods, contaminants are typically assumed to be present at half the detection limit (Vannort & Thomson 2005). If detection limits are high and the TDI relatively low, then this could lead to an overly conservative estimate of background exposure. For example, Cavanagh & Proffitt (2005) estimated the dietary arsenic intake of a child to be 0.38 μg/kg bw/day, which is greater than the selected TDI of 0.3 μg/kg bw/day. Closer inspection of the total dietary survey data indicated that arsenic was not detected in many foodstuffs, but the detection limit for some foodstuffs was reasonably high, likely resulting in an overestimate of arsenic intake.

Salcor (2003) also subtracts background exposure from the TDI for dioxins and allocates 100% of the residual to soil exposure. PDP (2003, 2004) used a similar approach, namely that background exposure is subtracted from the TDI and the residual is allocated to soil exposure – although in this case, less than 100% of the residual is allocated to exposure from soil.

Soil ingestion pathway

Soil ingestion is usually the primary route of exposure to soil contaminants, especially for children. While a range of soil ingestion rates are used internationally, all relevant New Zealand documents have used soil ingestion rate provided in the *Timber Treatment Guidelines* (100 mg/day, Table 20) for all residential scenarios except the high-density residential scenario. A lower ingestion rate has been used in some documents for high-density residential housing, to reflect the generally lower access to soil in high-density housing.

Produce-consumption pathway

A number of documents have used different parameters for the produce consumption pathway to those provided in the *Timber Treatment Guidelines*. There are three main areas where parameters differ: amount and type of produce consumed, the dry weight of produce, and determination of plant uptake.

Amount and type of produce consumed: Only consumption of vegetables is typically taken into account in the derivation of soil guideline values. While fruit is included in the amount of produce-consumed, uptake and translocation of contaminants to fruit (in fruit trees) is considered to be negligible (MfE 1997, 1999; MfE & MoH 1997) and it does not contribute to assumed contaminant intake. Different proportions of vegetables (including the proportion of root and leafy vegetables) and fruit consumed have been assumed in the different industry-based guidelines (see earlier discussion on each document). PDP (2004) and Cavanagh (2004) used the amount and proportion of vegetables specified in the *Timber Treatment Guidelines*. In contrast, Cavanagh & Proffitt (2005) determined the amount of vegetables consumed by an average child and adult from simulated diet data developed for the 2003/04 New Zealand Total Diet Survey (Brinsdon 2004), and determined consumption-weighted dry weights (refer to Appendix 4 for more detail). These parameters were also used in MfE (2006).

Typically, 10% and 50% of produce consumed is assumed to be home-grown for standard and rural residential exposure scenarios, respectively. Cavanagh & Proffit (2005) also derived guideline values assuming no consumption of home-grown produce, and 5% of produce consumed was home-grown. High-density residential exposure scenarios assume that no home-grown produce is consumed.

Dry weight of produce: The dry weight of produce is used to convert between the amount of produce consumed, which is typically expressed on a fresh-weigh basis, and the plant bioconcentration factor (concentration in plant / concentration in soil), which is typically expressed on a dry-weight basis. All industry-based guidelines assume that produce has a dry weight equal to 20% of the fresh weight. Cavanagh (2003, 2004b) used a dry weight of 8.5%, based on the average of dry weight of vegetables in US EPA (1996), to derive an interim soil guideline value for dieldrin. Cavanagh & Proffitt (2005) determined consumption-weighted dry weights for produce consumed by New Zealand adults and children, which was also used in MfE (2006).

Plant uptake: There is surprising variability in the methods used to determine plant-uptake of contaminants. The *Timber Treatment Guidelines* use an equation sourced from ECETOC (1990) to determine plant uptake of inorganic contaminants. Errors in the application of this equation in the *Timber Treatment Guidelines* have previously been noted (Cavanagh 2004 and Appendix 3). The inverse of the bioconcentration factors (to correct for methodological errors in the produce-consumption pathway) calculated in the *Timber Treatment Guidelines* was used by PDP (2004) in the derivation of soil guideline values for copper. The *Timber Treatment Guidelines, Gasworks Guidelines* and Salcor (2003) used the Travis & Arms (1988) model to estimate plant uptake of organic contaminants, while the *Petroleum Hydrocarbon Guidelines* used the model developed by Ryan et al. (1988). In addition, all industry-based guidelines have assumed a difference in uptake between leafy vegetables and root vegetables (e.g. the *Timber Treatment Guidelines* assumes that uptake in leafy vegetables is 5× less than that of root vegetables although the basis for this assumption is unclear), but in different proportions. In contrast, Cavanagh (2003, 2004) and Cavanagh & Proffitt (2005) assume a single bioaccumulation factor for contaminant uptake of root and leafy vegetables, and use experimental data to determine appropriate contaminant-specific bioaccumulation factors.

Dermal parameters

The primary differences in the dermal parameters used in different documents relate to soil adherence factors and skin surface area. Most documents have used the parameters provided in the *Timber Treatment Guidelines,* but some (Cavanagh 2003; Cavanagh & Proffitt 2005; *Sheep-dip Guidelines*; NESTRG (MfE 2005)) have used different values. These latter documents have used updated soil adherence values from the US EPA (2004), which represent the most recent and comprehensive dataset. The US EPA collated information on soil adherence from a range of activities and occupations for children and adults. From these data they recommended that a soil adherence factor of 0.2 mg/cm^2 represents a reasonable maximum exposure for children, based on data from children playing at daycare centres and in wet soil. The recommended soil adherence factor for adults is 0.07 mg/cm^2, and is based on data from gardening activities (US EPA 2004). In addition, various exposure durations, ranging from 8 to 24 hours/day, have been used (Table 20). The shortened exposure durations were considered to represent a more credible length of time contaminated soil is in contact with the skin.

Cavanagh (2003), Cavanagh & Proffitt (2005), and the NESTRG (MfE 2005) also use slightly different values for skin surface area.

Inhalation pathway

Exposure via inhalation of particulates is considered in a number of documents and the same parameters used in the *Timber Treatment Guidelines* have generally been used (Table 20). However, the *Gasworks Guidelines* and the *Petroleum Hydrocarbon Guidelines* consider exposure via inhalation of volatiles only. Other documents (*Sheep-dip Guidelines;* NESTRG methodology; Cavanagh 2003; Cavanagh & Proffitt 2005) consider that exposure via inhalation of particulates is negligible and therefore have not included this pathway. Where inhalation of particulates has been included (e.g. *Timber Treatment Guidelines*; PDP 2004) this pathway is demonstrated to be a negligible route of exposure for the residential scenario.

Agricultural/horticultural land

The agricultural/horticultural exposure scenario has only been considered in the existing industry-based guidelines. The major differences between different documents is in the way in which guideline values for the produce-consumption pathway were calculated (discussed above), and the inclusion of potential consumption of organic contaminants via milk and meat produce in the *Timber Treatment Guidelines* (Table 21).

Table 21 Parameters used in the derivation of soil guideline values for threshold and non-threshold contaminants for the agricultural/horticultural exposure scenario

Parameter	TTG	GWG	PHG
Exposure frequency (d/yr)	350	350	350
Exposure duration – threshold (yr)	6	6	6
Exposure duration – non-threshold (yr)	30[1]	30[1]	30[1]
Averaging time – non-threshold[2](yr)	70	70	70
Body weight child (kg)	15	15	15
Body weight adult (kg)	70	70	70
Percentage of TDI allocated to soil	var	100	100
Ingestion pathway			
Soil ingestion rate – child (mg/d)	100	100	100
– adult (mg/d)	25	25	25
Produce ingested[3] – child (kg/d)	0.13	0.13	0.13
– adult (kg/d)	0.45	0.45	0.45
– proportion[4] (%)	100	100	100
Milk ingested – child (kg/d)	-	-	-
– adult (kg/d)	0.302[5]	-	-
– proportion[4] (%)	-	-	-
Meat ingested – child (kg/d)	-	-	-
– adult (kg/d)	0.246[5]	-	-
– proportion[4] (%)	-	-	-
Dermal pathway			
Surface area – child (cm^2)	2625	2625	2625
– adult (cm^2)	4700	4700	4700
Soil adherence factor (mg/cm^2)	1	1	1
Skin absorption factor	CS	NS	CS
Inhalation pathway			
Inhalation rate – child (m^3/d)	3.8	3.8	3.8
– adult (indoor) (m^3/d)	15	15	15
– adult (outdoor) (m^3/d)	20	20	20
Particulate concentration ($\mu g/m^3$)	20[6]	20[6]	20[6]
Additional factors	0.75[7]	0.75[7]	0.75[7]

[*] Refer to Table 1 for source documents and acronyms.

Var – Variable; NS – Not specified; CS – Contaminant specific

[1] Includes 6 yrs as a child; [2] Averaging time for threshold contaminants is the same as the exposure duration; [3]Fresh weight; [4] Proportion grown/sourced on-site; [5]Pentachlorophenol only; [6]This is used to derive a particle emission factor of $2.5x10^8$, which is used to estimate inhalation exposures assuming 20% of dust is contaminated soil; [7] Proportion retained in lungs.

Parks and recreational land use

A parks and recreation exposure scenario has been considered in a number of documents (Table 2). For the most part the parameters specified in the *Gasworks Guidelines* have been used, although some differences exist (Table 22). Specifically, a reduced exposure frequency is specified in the NESTRG methodology, as well as other parameters unrelated to the exposure scenario (e.g. adult body weight, skin surface area).

Table 22 Parameters used in the derivation of soil guideline values for threshold and non-threshold contaminants for the parks and recreational exposure scenario*

Parameter	GWG	Salcor	SDG	NESTRG
Exposure frequency (days/year)	350	350	350	200
Exposure duration – threshold (year)	6	6	6	30[1]
Exposure duration – non-threshold (year)	30[1]	-	30[1]	30[1]
Averaging time – non-threshold[2] (year)	70	-	70	70
Body weight – child (kg)	15	15	15	15
– adult (kg)	70	-	70	75
Percentage of TDI allocated to soil	100	var	100	100
Ingestion pathway				
Soil ingestion rate – child (mg/day)	50	50	50	50
– adult (mg/day)	10	-	10	10
Dermal pathway				
Surface area – child (cm^2)	2625	2625	2625	1700
– adult (cm^2)	4700	-	4700	5000
Soil adherence factor (mg/cm^2)	1	0.5	0.2	0.2
Absorption factor	CS	CS	CS	CS
Inhalation pathway				
Exposure duration (hr/d)	5?	5?	-	-
Inhalation rate – child (m^3/day)	1.1[9]	1.1[9]	-	-
– adult (m^3/day)	2.4[9]	-	-	-
Particulate concentration ($\mu g/m^3$)	-	26[3]	-	-
Additional factors	-	0.75[4]	-	-

* Refer to Table 1 for source documents and acronyms.

'-' – not applicable; CS – contaminant specific

[1] Includes 6 yrs as a child; [2] Averaging time for threshold contaminants is the same as the exposure duration; [3]This is used to derive a particle emission factor of $2.5x10^8$, which is used to estimate inhalation exposures assuming 20% of dust is contaminated soil; [4] Proportion retained in lungs.

In addition, a different soil adherence factor, based on updated values discussed above, was used in the *Sheep-dip Guidelines* and in the NESTRG methodology. Both of these documents also consider that exposure via inhalation of particulates is negligible and therefore have not included this pathway. Egis (2001) also provide soil guideline values for a recreational setting (which are based on protection from off-site impacts, and protection of groundwater) although no details regarding the derivation of soil guideline values for protection of human health are provided for this scenario.

Only Salcor (2003) considers exposure via inhalation of particulates. The *Gasworks Guidelines* consider exposure via inhalation of volatiles only, while the *Sheep-dip Guidelines* and the NESTRG methodology consider that exposure via inhalation of particulates is negligible and therefore have not included this pathway.

Commercial and industrial land-use

Commercial and industrial land-use has been considered in several of the documents and for the most part the parameters specified in the *Timber Treatment Guidelines* have been used, although some differences exist (Table 23).

Table 23 Parameters used in the derivation of soil guideline values for threshold and non-threshold contaminants for the commercial and industrial exposure scenario*

Parameter	TTG	GWG	PHG	Salcor	SDG	TDC	NESTRG
Exposure frequency (days/year)	240	240	240	240	240	240	240
Exposure duration (year)	20	20	20	20	20	20	20
Averaging time – non-threshold [1] (year)	70	70	70	70	70	70	70
Body weight (kg)	70	70	70	70	70	70	75
Percentage of TDI allocated to soil	var	100	100	var	var	100	var
Ingestion pathway							
Soil ingestion rate (mg/day)	25	25	25	25	25	25	25
Dermal pathway							
Surface area (cm^2)	4700	4700	4700	4700	4700	4700	1700
Soil adherence factor (mg/cm^2)	1	1	1	1	0.2	1	0.2
Absorption factor	CS	CS	NS, CS	CS	CS	CS	CS
Inhalation pathway							
Inhalation rate – indoor (m^3/day)	-	10	-	-	-	-	-
– outdoor (m^3/day)	9.6	10	10	9.6	-	9.6	-
Particulate concentration ($\mu g/m^3$)	142[2]	-	-	142[2]	-	142[2]	-
Additional factors	0.75[3]	-	-	0.75[3]	-	0.75[3]	-

[*] Refer to Table 1 for source documents and acronyms.

'-' – not applicable; NS – not stated; CS – contaminant specific

[1] Averaging time for threshold contaminants is the same as the exposure duration; [2]This is used to derive a particle emission factor of 2.9 x 10^7, which is used to estimate inhalation exposures assuming 50% of dust is respirable and 50% of dust is contaminated soil; [3] Proportion retained in lungs.

Specifically, a different soil adherence factor is used in the *Sheep-dip Guidelines* and the NESTRG methodology. In addition, the NESTRG methodology uses a different adult body weight and skin surface area. The *Gasworks Guidelines* and *Petroleum Hydrocarbon Guidelines* consider exposure via inhalation of volatiles only. Similarly, the *Sheep-dip Guidelines* and the NESTRG methodology consider that exposure via inhalation of particulates is negligible and therefore have not included this pathway.

Maintenance/excavation workers

All industry-based guidelines have included a maintenance/excavation scenario, although in some cases it is merged with the commercial and industrial land use scenario (*Timber Treatment Guidelines, Gasworks Guidelines*), while in other cases it remains a separate exposure scenario (e.g. *Petroleum Hydrocarbon Guidelines*, Salcor and TDC (Egis 2001). With the exception of the landfill-operator scenario considered in Egis (2001), the parameters specified in the *Timber Treatment Guidelines* have been used (Table 24). For this scenario, an exposure frequency of 250 days/year is used, while all other parameters remain the same.

Table 24 Parameters used in the derivation of soil guideline values for threshold and non-threshold contaminants for the parks and recreational exposure scenario*

Parameter	TTG	GWG	PHG	Salcor	TDC	
					Excavation	Landfill
Exposure frequency (days/year)	50	50	50	50	50	250
Exposure duration (year)	20	20	20	20	20	20
Averaging time – non-threshold[1] (year)	70	70	70	70	70	70
Body weight (kg)	70	70	70	70	70	70
Percentage of TDI allocated to soil	var	100	100	var	100	100
Ingestion pathway						
Soil ingestion rate – (mg/day)	100	100	100	100	100	100
Dermal pathway						
Surface area (cm^2)	4700	4700	4700	4700	4700	4700
Soil adherence factor (mg/cm^2)	1.5	1.5	1.5	1.5	1.5	1.5
Absorption factor	CS	CS	NS, CS	CS	CS	CS
Inhalation pathway						
Inhalation rate – (m^3/day)	20	10	-	9.6	9.6	9.6
Particulate concentration ($\mu g/m^3$)	280[2]	-	-	280[2]	280[2]	280[2]

* Refer to Table 1 for source documents and acronyms.

'-' – not applicable; var – variable; NS – not specified; CS – contaminant specific.

[1] Averaging time for threshold contaminants is the same as the exposure duration; [2] This is used to derive a particle emission factor of 0.9×10^7 m^3/kg, which is used to estimate inhalation exposures assuming 50% is respirable and 80% is contaminated dust.

5.6 Comparison of contaminant-specific information

In addition to differences in the methodology used in individual documents, differences in the contaminant-specific-parameters values also contribute to differences in the derived soil guideline values. These differences may be in the classification of a contaminant as a threshold or non-threshold contaminant, difference in the TDI used, the dermal absorption factor, or the extent of plant uptake. The difference in the parameters used for arsenic, copper lead, benzo(a)pyrene, dieldrin, and DDT are discussed below. These contaminants have been considered in a number of the documents.

Arsenic

Soil guideline values for arsenic have been discussed in a number of documents (Table 1). With the exception of Cavanagh & Proffitt (2005) and Cavanagh (2006), the parameters, or the guideline values (*Sheep-dip Guidelines*), provided in the *Timber Treatment Guidelines* have been used (Table 25). The *Timber Treatment Guidelines* considered that arsenic was a non-threshold contaminant while Cavanagh & Proffitt (2005) and Cavanagh (2006) concluded that, on the basis of current toxicological data, arsenic should be considered as a threshold contaminant. These documents used the TDI provided in UK DEFRA & EA (2002), and allocated 20% of the TDI to exposure from soil as the estimated background exposure was greater than 80% of the TDI.

Table 25 Summary of contaminant-specific parameters used in the derivation of soil guideline value for arsenic*.

Parameter	TTG	SDG[1]	ARC	ACC	CCC	UW
Soil guideline value	30	30	9	76	9	95[2]
Tolerable daily intake (µg/kg-bw/day)	-	-	0.3	0.3	0.3	
Index dose (µg/kg-bw/day	0.067	0.067	-	-	-	0.067
Cancer slope factor (1/(mg/kg-bw/day))	0.15	0.15	-	-	-	0.15
Cancer slope factor (1/(mg/kg-bw/day) inhalation	15	15	-	-	-	15
Percentage of TDI allocated to soil	100	100	20	100	20	100
Plant bioaccumulation factor	0.07	0.07	0.009	-	0.009	-
Skin absorption factor	-	-	-	0.006	-	-

* Refer to Table 1 for source documents and acronyms.

[1] This documents use the guideline values provided in the *Timber Treatment Guidelines*; [2] Modified exposure frequency and no produce consumption assumed; [3] Biaccumulation factor for roots, contaminant concentrations in leafy vegetables are assumed to be 20% of root vegetables; [4] Default value in the model RISC

Copper

Several of the documents provide soil guideline values for copper (Table 1); all consider copper as a threshold contaminant and use the same TDI. However, the proportion of the TDI allocated to exposure from soil varies (Table 26). While the *Timber Treatment Guidelines* allocate 10% of the TDI to soil, nominally to be consistent with the Drinking Water Standards, PDP (2003, 2004) and Cavanagh & Proffitt (2005) determined a background exposure to copper and subtracted this from the TDI. PDP (2003, 2004) allocated less than 100% of the residual to exposure from soil, with 50% of the TDI allocated. In contrast, Cavanagh & Proffitt (2005) allocated 100% of the residual to exposure from soil.

Table 26 Summary of contaminant-specific parameters used in the derivation of soil guideline values for copper.

Parameter	TTG	ACC	CCC	HDC	UW
Soil guideline value	130	>10 000	>10 000	2300	>10 000[1]
Background exposure (mg/kg-bw/day)	-	-	0.044	0.1	0.1
Tolerable daily intake (mg/kg-bw/day)	0.5	0.5	0.5	0.5	0.5
Percentage of TDI allocated to soil	10	10	72	50	50
Plant bioaccumulation factor	0.28[2]	-	[3]	0.28[2]	-
Skin absorption factor	-	0.006[4]	-	-	-

* Refer to Table 1 for source documents and acronyms.

[1] Modified exposure frequency and no produce consumption assumed;[2] Biaccumulation factor for roots, contaminant concentrations in leafy vegetables are assumed to be 20% of root vegetables; [3]The concentration of copper in produce was set at 30 mg/kg, based on the concentration at which phytoxic effects are observed. At this concentration intake via consumption of produce is <5% TDI; [4]Default value in the model RISC

Further, in contrast to using a plant bioaccumulation factor, Cavanagh & Proffitt (2005) set the concentration of copper in produce at 30 mg/kg, based on the concentration at which phytotoxic effects are observed. At this concentration, intake via consumption of produce is <5% of the TDI for both children and adults and so was considered to be a negligible source of exposure.

Lead

Several of the documents provide a review or derive soil guideline values for lead (Table 1). For the most part these documents refer to lead guideline values developed in the United States or the United Kingdom, largely as these countries have developed soil guideline values on the basis of blood lead concentrations and soil concentrations (US EPA 1994a, b; UK DEFRA and EA 2002). Tonkin & Taylor (2006) derived soil guideline values for lead using the Leadspread model of the California Department of Toxic Substances Control, which relates blood lead levels to exposure from soil. Cavanagh (2005) and Cavanagh & Proffitt (2005) provide a good overview of the derivation of soil guideline values for lead (Table 27).

Table 27 Contaminant-specific parameters used to derive soil guideline values for lead*

Parameter	Biosolids Guidelines	CCC
Soil guideline values (mg/kg)	300	270 (460)
Background exposure (mg/kg-bw/day)	-	0.0003
Tolerable daily intake (mg/kg-bw/day)	0.0025	0.0025
Cancer slope factor (1/(mg/kg-bw/day))	-	-
Bioavailable fraction	-	100/60
Percentage of TDI allocated to soil	-	88
Plant bioaccumulation factor	-	-
Skin absorption factor	-	-

* Refer to Table 1 for source documents and acronyms.

Only the *Biosolids Guidelines* and Cavanagh & Proffitt (2005) derive soil guideline values for lead, so only the parameters used in these documents are shown in Table 15. The *Biosolids Guidelines* indicates that a value of 280 mg/kg was derived using the *Timber Treatment Guideline* methodology for soil ingestion. This was close to 300 mg/kg that had been determined via a US EPA risk assessment process, and the Department of Health (1992) value (NZWWA 2003). Cavanagh & Proffitt (2005) derived values for lead using an updated and revised version of the *Timber Treatment Guideline* methodology assuming that 100% and 60% of the lead was bioavailable.

Benzo(a)pyrene

Soil guideline values for benzo(a)pyrene (BaP) (Table 28) are derived in the *Petroleum Hydrocarbon Guidelines* and the *Gasworks Guidelines*, and by Cavanagh & Proffitt (2005). Key differences in the contaminant-specific parameters for benzo(a)pyrene are the toxicological intake used by Cavanagh & Proffitt (2005) and the plant bioaccumulation factor used in all documents.

Cavanagh & Proffitt (2005) undertook a review of available toxicological data and concluded that more recent data was appropriate to use. These authors based plant uptake on available experimental results. In contrast, the *Petroleum Hydrocarbon Guidelines* and the *Gasworks Guidelines* use models to estimate plant uptake. As discussed in section 5.5, these models differ although both methods are based on the log K_{ow}[1] of the organic contaminant. Slightly different values are used in the two documents – the *Petroleum Hydrocarbon Guidelines* use a log K_{ow} of 6.04, while the *Gasworks Guidelines* use K_{ow} of 9.55×10^5, which gives a log K_{ow} of 5.98, which also contributes to the difference in the estimated plant bioaccumulation factor.

Table 28 Summary of contaminant-specific parameters used in the derivation of soil guideline value for BaP*

Parameter	GWG	PHG	ACC	CCC
Guideline value	1	0.27	4.6	6
Cancer slope factor (1/(mg/kg-bw/day))	7.3	7.3	7.3	1.2
Index dose (ng/kg.bw/day)	1.4	1.4	1.4	8.3
Skin absorption factor	0.01	0.01[1]	0.01	0.022
Plant bioaccumulation factor	0.027[2]	0.018[3]	-	0.038[4]

[*] Refer to Table 1 for source documents and acronyms.

[1] Not given in MfE (1999). Back-calculated from dermal pathway value of 7.5 mg/kg; [2] Given as a fresh-weight Plant Uptake Factor, weighted for consumption of root and leafy vegetables, but converted from dry weight assuming a dry-weight content of 20%; [3] Appendix F (MfE 1999).; [4]Dry weight

DDT

Soil guideline values for DDT have been considered in a number of the documents (Table 1). In all cases, this value is considered to apply to the sum of DDT and its metabolites DDD and DDE. All documents assume DDT is a threshold contaminant although PDP (2003) also provides cancer-slope factors. With the exception of PDP (2003), all documents have used a TDI of 0.0005 mg/kg (Table 29) sourced from US EPA (2001) and Baars et al. (2001). PDP (2003) use the TDI determined by JMPR (2003), which is also used in the New Zealand Drinking Water Guidelines (MoH 2005).

Different values for plant uptake have been used. PDP (2004) based uptake on the median value for DDT provided in US EPA (2000, cited in PDP 2004). In contrast MfE (2006) used a value of 0.136 based on median of three values provided for DDE, the primary metabolite of DDT, provided in US EPA (2005). TDC (Egis 2001) used the Travis & Arms (1988) model to estimate plant uptake.

Table 29 Summary of contaminant-specific parameters used in the derivation of soil guideline values for DDT in different documents*.

Parameter	SDG	HDC	TDC	UW
Guideline value	28	25	190	47
Tolerable daily intake (mg/kg-bw/day)	0.0005	0.0005	0.002	0.01
Cancer slope factor (1/(mg/kg-bw/day))	-	-	-	0.34
Cancer slope factor (1/(mg/kg-bw/day))inhalation-	-	-	-	0.34
Skin absorption factor	0.01	0.02	0.03	NS
Plant bioaccumulation factor	0.136	0.028	0.011[1]	NA

[*] Refer to Table 1 for source documents and acronyms. [1] Converted from a reported wet weight value assuming 20% dry weight of produce

[1] K_{ow} is the octanol-water partition coefficient and a measure of the relative affinity an organic compound has to bind to organic material (e.g. in soil) or dissolve in water.

Dieldrin

Soil guideline values for dieldrin were derived by MfE (2006), Egis (2001), and Cavanagh (2004c). All documents consider dieldrin as a threshold contaminant and use the same TDI and the same dermal absorption factor (Table 30). The primary difference between the documents is in the plant bioaccumulation factor used. Cavanagh (2003) used the median value of 0.024 reported in US EPA (2003), while MfE (2006) uses the median value of 0.41 reported in an update of this document (US EPA 2005). Egis (2001) used the Travis & Arms (1988) model to estimate plant uptake.

Table 30 Summary of contaminant-specific parameters used in the derivation of soil guideline values for dieldrin.

Parameter	SDG	ARC	TDC
Guideline value	2.7	6	5
TDI	0.0001	0.001	0.0001
Skin absorption factor	0.1	0.1	0.1
Plant bioaccumulation factor	0.41	0.024	0.0025[1]

[*] Refer to Table 1 for source documents and acronyms.

[1] Converted from a reported wet-weight value assuming 20% dry weight of produce.

5.7 Comparison of methodologies to provide protection for ecological receptors

Several of the documents provide guideline values for the protection of ecological receptors (Table 1). While some (Cavanagh & Booth 2003; Cavanagh 2006; Cavanagh & O'Halloran 2006) were developed specifically for the protection of ecological receptors on contaminated land, the *Biosolids Guidelines* and the waste acceptance criteria were not. However, given that the aim of the soil limits provided in the *Biosolids Guidelines* is the long-term protection of soil quality these values could be applied to contaminated land. In contrast, the waste acceptance criteria were developed to provide protection thus their application to contaminated land stems more from the perspective of potential restrictions on disposal of contaminated soil to landfill. Given the different basis for protection, the methodology for the waste acceptance criteria is not discussed further.

Cavanagh & O'Halloran (2006) and Cavanagh (2006) updated the methodology used in Cavanagh & Booth (2003), and used statistical extrapolation methods to derive soil guideline values when sufficient data were available. In addition, the uncertainty factors used when insufficient data were available were updated. This methodology is similar to that used in the ANZECC/ARMCANZ water quality guidelines (ANZECC/ARMCANZ 2000), but differs significantly from that used in the *Biosolids Guidelines*. The soil limits in the *Biosolids Guidelines* were based on the lowest observed adverse effect concentrations (LOAEC) determined from a review of the available literature.

6. Derivation of Guideline Values Using NESTRG Methodology

To date no soil guideline values have been derived using the methodology proposed by NESTRG (MfE 2005). As such, there has been no comparison of what influence changes in the methodology would have on the final soil guideline values. This section derives soil guideline values for arsenic, copper and benzo(a)pyrene, key contaminants of concern in major urban areas. As different toxicological intakes have been used for arsenic and benzo(a)pyrene in the different New Zealand documents, soil guideline values are derived both using the toxicological intakes in existing industry-based guidelines (*Timber Treatment Guidelines*, *Petroleum Hydrocarbon Guidelines*) and those in Cavanagh & Proffitt (2005) based on a recent review of the toxicological literature. All other contaminant-specific parameters are those used in Cavanagh & Proffitt (2005).

A description of the proposed exposure scenarios in the NESTRG methodology is provided in Table 31, while the specific parameters used in each scenario are provided in Tables 20–24. Table 32 provides a summary of the contaminant-specific parameters used to derive soil guideline values in this section, while Table 33 provides a summary of the soil guideline values derived using the NESTRG methodology. Soil guideline values derived for individual pathways of exposure are summarised in Appendix 5.

As can be seen from Table 33, the choice of toxicological intake for an individual contaminant makes a difference to the final guideline value. Using the toxicological intakes of Cavanagh & Proffitt (2005) yields lower soil guideline values for arsenic, although higher guideline values for BaP. The NESTRG methodology results in a significantly different soil guideline value for arsenic compared with that derived in Cavanagh & Proffitt (2005) for the standard residential scenario (9 mg/kg) even though the same contaminant-specific and exposure parameters, with the exception of exposure duration, were used. This shows the influence on the final soil guideline value of the change in exposure duration for threshold contaminants in the NESTRG methodology. The soil guideline value for arsenic for a standard residential scenario using the Cavanagh & Proffitt (2004) toxicological intake is close to 30 mg/kg, the soil guideline value presented in the *Timber Treatment Guidelines*, despite known errors in the latter methodology. In contrast, the difference between soil guideline values for BaP derived using the NESTRG methodology and those presented in existing industry-based guidelines (*Petroleum Hydrocarbon Guidelines*, *Gasworks Guidelines*) primarily reflects the difference in the estimation of exposure via produce consumption, when the same toxicological intake is used.

Soil guideline values for copper for all residential scenarios are much higher than those presented in the *Timber Treatment Guidelines* – this largely reflects consideration of protection of human health only, and allocation of a greater proportion of the TDI to exposure from soil, in addition to the change in exposure duration for threshold contaminants.

Soil guideline values for all contaminants for the industrial exposure scenario are generally higher (less conservative) using the NESTRG methodology compared with those values presented in existing industry-based guidelines, when the same toxicological intake is used. This difference is largely due to the exclusion of exposure via inhalation in the NESTRG methodology. In contrast, the *Timber Treatment Guidelines* include exposure via inhalation of particulates, while the *Petroleum Hydrocarbon Guidelines* and the *Gasworks Guidelines* include exposure via inhalation of volatiles. However, while this appears to suggest that inhalation could be a significant route of exposure, the intake of particulates, at the concentration specified in the *Timber Treatment Guidelines* (142 $\mu g/m^3$), and inhalation rate of 10 m^3/day, is ~1.4mg or ~6% of the soil ingestion rate. This indicates that inhalation of particulates should be considered negligible. Further work is required is establish the significance of exposure via inhalation of volatiles.

Table 31 Exposure scenarios proposed for use in the derivation of generic soil numeric values for metals and semi-volatile contaminants in the NESTRG methodology*

Scenario	Description
Rural Residential	Rural residential land use, including produce consumption
Urban residential	Standard residential block, including produce consumption
High-density residential	Urban residential block, excluding produce consumption, applicable to urban flats and apartments
Parks/Active recreational	Public and private green areas that are used for sports and recreation
Industrial (unpaved)[1]	Unpaved industrial sites; will also take into account paving of a proportion of the site

NESTRG = National Environmental Standard Technical Review Group

* An additional exposure pathway for consideration is a schools/kindergarten scenario, which will differ from both residential and parks/recreational scenarios.

[1]A commercial/Industrial (paved) scenario is not recommended for metals (with the possible exception of mercury) and semi-volatile contaminants due to the absence of soil contact in this scenario. However, this scenario should be considered for volatile contaminants.

Table 32 Summary of contaminant-specific parameters used in the derivation of soil guideline values using the NESTRG methodology

Parameter	Arsenic		Copper	Benzo(a)pyrene	
	C&P[1]	TTG[1]		C&P[1]	PHG[1]
Tolerable daily intake	0.0003	-	0.5	-	-
Cancer slope factor (1/(mg/kg-bw/day))	-	0.15	-	1.2	7.3
Index dose (µg/kg.bw/day)	-	0.067	-	0.0083	0.0014
Skin absorption factor	-	-	-	0.022	0.022
Plant bioaccumulation factor	0.009	0.009	[2]	0.038	0.038

[1] Refer Table 1. [2] The concentration of copper in produce was set at 30 mg/kg, based on the concentration at which phytotoxic effects are observed. At this concentration intake via consumption of produce is <5% TDI.

Table 33 Summary of soil guideline values derived using the NESTRG methodology

Substance	Rural residential	Urban residential	High-density residential	Parks/Active recreation	Industrial (unpaved)
Arsenic (C&P)	15	28	140	60	226
Arsenic (TTG)	40	74	365	142	881
Copper	>10 000	>10 000	>10 000	>10 000	>10 000
Benzo(a)pyrene (C&P)	1.8	5.6	49	22	115
Benzo(a)pyrene (PHG)	0.3	0.9	8	3.5	19

7. Conclusions

A number of documents currently available in New Zealand recommend or develop soil guideline values for the management of contaminated land at either a national or regional level. With the exception of cadmium and mercury, soil guideline values for all contaminants considered as priority 1 by NESTRG have been derived in existing documents. However, these documents may contain different soil guideline values for a given contaminant and land use as a result of differences in the methodology. The majority of these documents focus on protection of human health and use a variation of the *Timber Treatment Guidelines* methodology to derive guideline values. Variations largely include the use of different parameter values, primarily for the dermal exposure and produce-consumption pathways, and differences in the methodology used to estimate plant uptake of contaminants. In addition, different contaminant-specific parameters have been used in different documents. The influence of different parameter values, including contaminant-specific parameters, on the final soil guideline value reflects the importance of gaining a consensus on all parameters used in the derivation of soil guideline values to be applied at a national level.

A limited number of documents consider protection of ecological receptors. Documents that derive soil guideline values specifically for use in contaminated land management use the same general methodology. However, this methodology differs from that in the *Biosolids Guidelines*, which provide soil limits for land to which biosolids are applied but which could also be applied to contaminated land.

8. Recommendations

- Rederivation of existing soil guideline values using a common methodology and contaminant-specific parameters is required to ensure consistency in derived guideline values.
- Consensus is required on the toxicological intake (tolerable daily intake, slope factor) and other contaminant-specific parameters used in the derivation of soil guideline values. Agreement on the toxicological intake value should be reached with other agencies who use similar values (eg. MoH, MAF and ERMA).
- Consensus on the general methodology, including parameter values, used to derive soil guideline values is required.

9. Acknowledgements

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Appendix 1 Auckland City Council soil criteria

Table A1 Auckland City Council interim[1] soil screening criteria – human health

Contaminant	Human Health Guideline (mg/kg)	
	Residential	Parkland / Recreation[2]
Heavy metals		
Arsenic	30[3]	200
Cadmium	20[2]	40
Chromium (Trivalent)	600[3]	24 000
Copper	370[4]	2000
Lead	300[2,5]	600
Mercury	15[2]	30
Nickel	600[2]	600
Zinc	7000[2,5]	14 000
Polycyclic aromatic hydrocarbons		
Benzo[a]anthracene	0.62[6]	-
Benzo[b]fluoranthene	0.62[6]	-
Naphthalene	3[7]	> 40
Dibenzo[a,h]anthracene	0.06[6]	-
Indeno[1,2,3-c,d]pyrene	0.62[6]	-
Benzo(a)pyrene (equivalence)	0.27[8]	2
Total polycyclic aromatic hydrocarbons	20[2]	40
Polychlorinated biphenyls (PCBs)		
Polychlorinated biphenyls	0.22[6]	20
Pesticides		
DDT/DDE/DDD (total)	25[5]	400
Aldrin	10[2]	20
Dieldrin	6[5]	20
Lindane	0.44[6]	-
Heptachlor	10[2]	20
Chlordane	50[2]	100

[1] These Tier I investigation values are currently used on an interim basis by Auckland City Council. The values will be superseded by future National Environmental Standards (NES) for human health.

[2] NEPC (1999) standard residential with garden/accessible soil (home grown produce contributing 10% produce consumption

[3] *Timber Treatment Guidelines* (MfE & MoH 1997) residential (combination 50% home-grown produce).

[4] Value currently under review

[5] . Cavanagh (2004).

[6] USEPA Region 6. Note that current NZ guidelines for cancer risk acceptability differ from US guidelines by a factor of 10.

[7] Soil acceptance criteria in *Gasworks Guidelines* (MfE 1997) 50% home-grown produce.

[8] MfE Oil Industry guidelines (all pathways, <1 m, sandy silt).

Appendix 2 Suggested guidelines for residential soil subdivision in the Waikato Region

Table A2 Suggested soil guidelines for the Waikato Region (Nick Kim, Environment Waikato, September 2004)

	Human health	Protection of ecological receptors (usually, plants)	Joint human/ecological	Suggested default guideline to use
Arsenic	30[1, 2]	20[3]; 10–20[1]	-	**30[1]**
Cadmium	1[4, 5]	1[3]	-	**1**[4 5]
Chromium	18 000[1, 6, 7]	600[1, 3]	-	600[1, 8]
Copper	370[1, 9]	100[3]; 130[1, 10]	-	**370**[1, 9]
Lead	280[3, 11]; 400[12, 13]	-	70[14, 15]	**300**[3, 11]
Mercury	8[4, 16]	1[17]	6.6[14]	**1**[8, 17]
Nickel	50[18]	60[19]	50[20]	**50[18]**
Zinc	23 000[21]	300[19]	200[20]	**300[19, 22]**
DDT[24]	7.9[24]; 17.2[25]	-	0.7[20]	**7.9[26]**

References and commentary

1 *Timber Treatment Guidelines* (MfE & MoH 1997), table 5.17.

2 Figure for 10% home produce ingestion. Note that the derived figure for 50% home produce ingestion is 8.1 mg/kg, which is below natural arsenic concentrations of many soils.

3 *Biosolids Guidelines* (NZWWA 2003). Note that although these guidelines may appear to relate to agricultural soils, considerations relating to plant health are common between agricultural and residential soils. For some contaminants, residential guidelines were derived based on the methodology set out in the *Timber Treatment Guidelines* (MfE & MoH 1997).

4 UK DEFRA and EA (2002b). Selected in accordance with MfE (2003).

5 Note that the UK guidelines (UK DEFRA & EA 2002b) give three figures for cadmium, depending on soil pH: 1 mg/kg for pH 6, 2 mg/kg for pH 7, and 8 mg/kg for pH 8. This relates to the relationship between acidity and plant uptake in home produce. In the Waikato Region, soils tend to be below pH 6, and the guideline figure of 1 mg/kg applies. A mean soil pH figure over 83 pastoral, horticultural, arable, forest and background sites in the Waikato Region was pH 5.47.

6 Strictly speaking, this relates to chromium (III), but the common assumption is made that almost all chromium in typical soil will be in this oxidation state. Where the soil is associated with an industrial process that makes use of chromium, both chromium (III) and chromium (VI) should be tested for. Limits for chromium (VI) are much lower: 9 mg/kg for 50% home produce ingestion, and 25 mg/kg for 10% home produce ingestion.

7 Derived figure for 50% home produce ingestion. Note that the figure of 600 mg/kg was adopted because it is protective of plant health.

8 In terms of human health protection, it might be reasonably argued that the higher chromium and mercury figures are more applicable to residential soil. However, it is so rare to find chromium nearing 600 mg/kg, or mercury nearing 1 mg/kg that it seems appropriate to make use of the lower figures for protection of plant life as the usual default value. As the lower of the two options, the chromium value of 600 mg/kg is also the figure adopted in the *Health and Environmental Guidelines for Selected Timber Treatment Chemicals* (1997). Where 1 mg/kg mercury is exceeded, use of a higher risk-based limit (6.6 mg/kg) is not precluded.

9 This is the figure that was derived for protection of human health under 10% home produce ingestion. The copper guideline is under review by the Ministry for the Environment, due to methodological problems in the way it was derived in the *Timber Treatment Guidelines* (MfE & MoH 1997). A more reliable figure of 500 mg/kg (50% home produce ingestion) has been used in some parts of the Auckland Region, based on an appropriate risk methodology. However, this is not yet a nationally adopted figure, and until it (or something similar) is, the figure of 370 mg/kg for 10% home produce ingestion from the *Timber Treatment Guidelines* is recommended in the interim. Where this is exceeded, site-specific cases might be made.

10 This figure is specifically designed for protection of plant life, but is superceded by the newer 100 mg/kg figure from the *Biosolids Guidelines* [footnote 3]. As a result of the way the *Timber Treatment Guidelines* (MfE & MoH 1997) are laid out, 130 mg/kg is sometimes confused for the 10% home produce ingestion figure. In reality it was the lower of two estimates: one for produce ingestion, and one for plant health.

11 Residential land figure derived as part of development of guideline [footnote 3] using the methodology set out in the *Timber Treatment Guidelines* (MfE & MoH 1997). (This methodology is Government Policy.) For subdivisions, this is taken to supercede Ministry of Health advice provided in guideline (MoH 1998)[footnote 13].

12 MoH (1998). This guideline may still have relevance, particularly to already developed properties.

[13] Lead is a special-case contaminant where good science exists linking soil concentrations with blood lead levels in children. The figure of 400 mg/kg recommended by the Ministry of Health [footnote 13] strictly applies to soil replacement in high-contact areas. As a risk-based figure it supersedes the ANZECC (1992) threshold figure of 300 mg/kg. Where soils contain more lead than 400 mg/kg in an established area, soil removal may or may not be required. Consult guideline [footnote 13].

[14] CCME 2002. Selected in accordance with MfE (2003).

[15] Note that the average lead content of urban and suburban residential soil in New Zealand generally exceeds 70 mg/kg, due to former use of leaded petrol. An average for 80 Hamilton lawn soil samples was 75 mg/kg.

[16] The guidelines footnote [3] reference a Department of Health (1992) figure of 1 mg/kg, but this appears to be a threshold level and not risk-based.

[17] NEPC (Australia) 1999.

[18] UK DEFRA & EA 2002b. Selected in accordance with MfE (2003).

[19] *Biosolids Guidelines* (NZWWA 2003). Note that although these guidelines may appear to relate to agricultural soils, considerations relating to plant health are common between agricultural and residential soils. Figures given in these guidelines for nickel and zinc are set to protect against phytotoxicity.

[20] CCME (Canadian Councils for Ministers for the Environment) (2002). Selected in accordance with MfE (2003).

[21] US EPA (2001). Selected in accordance with MfE (2003).

[22] Human health will almost never be an issue with zinc: the more recent New Zealand figure of 300 mg/kg (designed to protect ecological receptors, see footnote [19]) has precedence over the Canadian figure of 200 mg/kg.

[23] Guidelines for DDT generally refer to the sum of detected isomers and breakdown products: DDT, DDE and DDD.

[24] This is the lowest peer-reviewed international risk-based guideline for protection of human health, using New Zealand's adopted tolerable excess cancer risk of 1 in 10^5. However, it has not ben formally adopted by any jurisdiction (Lowe & Jamall 1994).

[25] This is the lowest figure designed for protection of human health, and adopted by a jurisdiction (US EPA 2002), corrected for New Zealand's adopted tolerable excess cancer risk of 1 in 10^5. The US tolerable excess cancer risk is 1 in 10^6, so adjusting the guideline for New Zealand involves multiplying the US figure (1.72 mg/kg) by a factor of 10.

[26] When DDT is put through the methodology set out in the *Timber Treatment Guidelines* (MfE & MoH 1997), a figure of 8 mg/kg is derived based on 50% home produce ingestion (PDP 2003). For this reason, it is suggested that the available peer-reviewed figure of 7.9 mg/kg is more appropriate for New Zealand as an interim figure than the US EPA cancer-risk adjusted number of 17 mg/kg. It is also noted that residential soil remediation target for the Fruitgrowers site at Mapua was 5 mg/kg. Note further that approximately 27% of New Zealand pastoral soil still exceeds 0.7 mg/kg DDT, based on a large dataset of samples submitted for agricultural soil analysis: in this regard DDT is similar to lead as a common broad-scale contaminant.

Appendix 3 Error-check on equation producing target produce-concentration

The following discussion is modified from Cavanagh (2004a).

The *Timber Treatment Guidelines* use Equation A.1 sourced from ECETOC (1990) to estimate the contaminant concentrations in root vegetables:

$$C_{root} = C_s \times BCF_{root} \qquad (A.1)$$

where C_{root} = concentration of contaminant in plant root (mg/kg produce)
C_s = contaminant concentration in soil (mg/kg)
BCF_{root} = bioconcentration factor (concentration in root/concentration in soil)
given by: $\ln(Kd) = 3.02 - 0.85 \ln(BCF)$,
where Kd = distribution coefficient (ml/mg).

The *Gasworks Guidelines* and the *Timber Treatment Guidelines* determine a target produce concentration according to:

$$Cp \times Pr \times \frac{1}{BCF_{root}} + Cp \times Pl \times \frac{1}{BCF_{leafy}} = C_{soil} \qquad (A.2)$$

where Pr = proportion of root vegetables
Pl = proportion of leafy vegetables
BCF = bioconcentration factor = $C_{produce}/ C_s$ (A.3)
and $C_{produce}$= concentration in produce (leafy or root vegetable)
C_s = concentration in soil

This initially appears to be logically correct as it follows the same form as rearrangement of Equation A.3, which yields:

$$C_s = C_{produce}/ BCF_{produce} \qquad (A.4)$$

An alternative approach was used to check the mathematical consistency of the above equations, and starts by considering the total amount of contaminant ingested from consumption of produce. The amount ingested is given by the concentration in the produce multiplied by the amount of produce consumed, and is comprised of the amount ingested from root vegetables consumed, and the amount ingested from leafy vegetables consumed, and is given by:

$$Cp \times IP = C_{root} \times IP_{root} + C_{leafy} \times IP_{leafy}, \qquad (A.5)$$

where C_{root} = concentration of contaminant in root vegetables (mg/kg produce)
C_{leafy} = concentration of contaminant in leafy vegetables (mg/kg produce)
IP = total daily amount of produce consumed (kg/day)
IP_{root} = daily amount of root vegetables consumed (kg/day), given by Pr × IP
IP_{leafy} = ingestion rate of leafy vegetables (kg/day), given by Pl × IP.

Incorporating equation A.3 and substituting for IP_{root} and IP_{leafy} yields:

$$Cp \times IP = Cs \times BCF_{root} \times Pr \times IP + Cs \times BCF_{leafy} \times Pl \times IP,$$

which simplifies to:

$$Cp \times IP = Cs \times IP \times \{(BCF_{root} \times Pr) + (BCF_{leafy} \times Pl)\}$$

and $$Cs = \frac{Cp}{(BCF_{root} \times Pr) + (BCF_{leafy} \times Pl)} \qquad \text{(A.6)}$$

Equations A2 and A.6 are not equivalent, and it appears that the source of error lies in the incorporation of the proportion of root and leafy vegetables to estimate C_s. Given that Equation A.6 can be mathematically proven, this equation is considered to be correct. This is also the same form as that provided in appendix 4F of the *Petroleum Industry Guidelines* to determine soil contaminant concentrations for the produce consumption pathway.

Appendix 4 Determination of amount of produce consumed and produce dry weight

The following is modified from Cavanagh & Proffitt (2005).

Typically, only the consumption of vegetables is taken into account in the derivation of soil guideline values (e.g. UK, Netherlands, Canada). This appears to be largely a consequence of the fact that vegetables, as opposed to fruit, are more widely grown in residential gardens. Fruit is considered in the New Zealand industry-based guidelines, but it does not contribute to the estimated contaminant intake via produce because uptake and translocation to fruit (in fruit trees) is considered to be negligible (MfE & MoH 1997; MfE 1999). Given that growing fruit is unlikely to be a significant occurrence in urban residential areas, estimation of the amount of produce consumed is based on the consumption of vegetables only. Table A4.1 shows the amount of produce consumed by different age and gender groups based on simulated diets. For this study, an average adult and an average child were considered to be the critical receptors.

Table A4.1 Amount of fruit and vegetables consumed (g/day) by different age–gender groups based on simulated diets for the New Zealand 2003/04 Total Diet Surveys.

Produce	Young male (19–24 yrs)	Male 25+ yrs	Female 25+ yrs	Average adult[1]	Child 5–6 yrs	Child 1–3 yrs	Child 6–12 mths	Average child[2]
Vegetables	224	294	232	254	115	63	42.5	77
Fruit	110	138	141	136	140	77	62.5	95
Total	336	432	373	390	256	140	105	173
Body weight[3]	70	80	65	70	20	13	10	15

Source: Adapted from Brinsdon (2004).

[1] Adjusted for difference in body weight prior to averaging and converted to the amount consumed by a 70-kg adult.

[2] Adjusted for difference in body weight prior to averaging and converted to the amount consumed by a 15-kg child.

[3] Vannoort and Thomson (2005)

The extent of uptake of contaminants by different vegetables is dependent on the individual vegetable. In the development of soil guideline values, vegetables are most frequently separated into root (e.g. carrots, potato) and above-ground (e.g. lettuce, peas) vegetables. The vegetables considered in the development of the simulated diets were grouped into root vegetables, ‘above-ground’ vegetables, and vegetables unlikely to be grown at home, as shown in Table A4.2.

Table A4.2 Vegetables considered in simulated diets, and their grouping

'Above-ground' vegetables	Root vegetables	Unlikely to be grown at home
Beans	Carrot	Avocado
Broccoli/Cauliflower	Kumara	Celery
Cabbage	Potato	Mushrooms
Capsicum		
Courgette		
Cucumber		
Lettuce		
Onion		
Peas		
Pumpkin		
Silverbeet		
Tomato		

Dry weights of individual vegetables (Table A4.3) were determined from the average of the values provided in US EPA (1996, 1997) and Alloway et al. (1988), with the exception of the dry weight of avocado. The dry weight of avocado was determined from Hofshi et al. (2000) who showed the average dry weight of the edible portion of avocado over a growing season.

Table A4.3 Vegetable dry weights

Vegetable	Dry weight
Avocado	0.25
Beans	0.094
Broccoli/cauliflower	0.089
Cabbage	0.083
Capsicum	0.15
Carrot	0.110
Celery	0.116
Courgette	0.035
Cucumber	0.079
Kumara	0.21
Lettuce	0.046
Mushrooms	0.082
Onion	0.124
Peas	0.145
Potatoes	0.210
Potatoes, with skin	0.167
Pumpkin	0.084
Silverbeet (spinach)	0.073
Tomato	0.058

Table A4.4 provides a summary of the amount of vegetables consumed by an average adult and child, using the above grouping. Plant uptake of contaminants is typically expressed on a dry-weight basis, and therefore requires conversion to the wet weights typically used to express the amount of produce consumed. However, the dry-weight content of different vegetables is also variable. The dry weight of individual vegetables (Table A4.3) and the amount of each vegetable consumed was used to determine the amount of produce consumed on a dry-weight basis (Table A4.4). This also enables derivation of consumption-weighted dry weights for the different types of vegetables, and for different receptors. The consumption-weighted dry weight content does not vary much for the different receptors (Table A4.4), with root vegetables having an average dry-weight content of about 0.18, and above-ground vegetables of 0.09.

The percentage of different vegetables types (root or above-ground) is also often used to estimate plant uptake. As can be seen from Table A4.4 the percentage of different types of vegetables consumed varies depending on whether it is expressed as wet weight or dry weight. As such, care must be taken to ensure the appropriate values are used in the derivation of soil guideline values.

Table A4.4 Amount of different vegetable groups consumed (g/day) and percentage of total vegetable by an average adult and average child, expressed on a dry or wet weight basis. Groups based on simulated diets for the New Zealand 2003/04 Total Diet Surveys.

Produce	Wet weight (g)		Dry weight (g)		Consumption-weighted dry - weight content (g dry wt/g wet wt)	
	Average adult	Average child	Average adult	Average child	Adult	Child
Root vegetable	110	42	21	7.6	0.19	0.18
Above-ground vegetables	133	31	11	2.8	0.09	0.09
Unlikely to be grown at home	10	3.6	1.4	0.57	-	-
Total	254	77	34	11	0.13	0.14

Source: Adapted from Brinsdon (2004).

Appendix 5 Soil guideline values for individual pathways of exposure

Table A5 Summary of soil guideline values (mg/kg) for individual pathways

Contaminant	Scenario	Soil ingestion	Dermal absorption	Produce ingestion	Combined [1]
Arsenic (C&P)	Rural/lifestyle	39	504	27	15
	Standard residential	39	504	136	28
	High-density urban residential	195	504	-	195
	Parks/recreation	68	880	-	68
	Industrial (unpaved)	273	2010	-	226
Arsenic (TTG)	Rural/lifestyle	100	1310	70	24
	Standard residential	100	1310	353	34
	High-density residential	510	1310	-	365
	Parks/recreation	160	2300	-	142
	Industrial (unpaved)	1060	7830	-	880
Copper	Rural/lifestyle	>10 000	>10 000	>10 000	>10 000
	Standard residential	>10 000	>10 000	>10 000	>10 000
	High-density urban residential	>10 000	>10 000	>10 000	>10 000
	Parks/recreation	>10 000	>10 000	>10 000	>10 000
	Commercial/ industrial	>10 000	>10 000	>10 000	>10 000
Benzo(a)pyrene (C&P)	Rural/lifestyle	12	222	2.1	2
	Standard residential	12	222	10.5	8
	High-density residential	63	222	-	49
	Parks/recreation	22	390	-	22
	Industrial (unpaved)	133	1330	-	115
Benzo(a)pyrene	Rural/lifestyle	2	36	0.3	0.3
	Standard residential	2	36	1.7	1.6
	High-density urban residential	10	36	-	8
	Parks/recreation	3.6	64	-	3
	Commercial/ industrial	22	220	-	19

[1] Inverse of the sum of inverses