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

Schedule B7

GUIDELINE ON

Health-Based Investigation Levels

This guideline provides general guidance in relation to health-based investigation levels in the assessment of site contamination.

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

This Schedule replaces Schedule 7a and Schedule 7b to the National Environment Protection (Assessment of Site Contamination) Measure 1999.

The National Environment Protection Council (NEPC) acknowledges the contribution of the National Health and Medical Research Council to the development of this Schedule.

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Health-based investigation levels

1 Introduction

1.1 Background

This document presents the health investigation levels (HILs) for soil and describes their derivation. Schedules B7a and B7b to the National Environment Protection (Assessment of Site Contamination) Measure (NEPM 1999) have also been updated and combined in this Schedule B7.

A review of the NEPM (1999) was carried out during 2005-2006 at the request of the National Environment Protection Council (NEPC). The review recommended changes to improve the effectiveness and efficiency of the NEPM by addressing technical, scientific and health risk issues raised by site assessors, consultants, land developers, auditors and the public (NEPC 2006).

The recommendations from the NEPM review that relate to the HILs are as follows:

- Recommendation 5 — revise existing HILs in the light of current knowledge, leading to more accurate numbers.
- Recommendation 6 — derive additional HILs for priority substances.
- Recommendation 7 — develop guidance to further clarify the use of HILs to counter their inappropriate use as remediation criteria.
- Recommendation 8 — develop HILs for a priority list of carcinogenic contaminants.
- Recommendation 15 — develop HILs, in a prioritised fashion, for all non-dioxin persistent organic pollutants (POPs) that are not addressed in the original NEPM (1999).

The requirement for additional HILs was also discussed at the 5th National Workshop on the Assessment of Site Contamination (NEPC 2003), at which some new HILs were proposed, and a list of possible candidate substances was produced.

This revised Schedule B7 is designed to address the findings of the NEPM review. It presents an expanded list of HILs in accordance with the above recommendations, and sets out the revised and updated methodology adopted to derive the HILs. The methodology presented here is also designed for use in site-specific risk assessment. Further guidance on site specific risk assessment is provided in Schedule B4 Guideline on site-specific health risk assessment methodology.

1.2 Purpose of HILs

The HILs are scientifically–based, generic assessment criteria designed to be used in the first stage (Tier 1) of an assessment of potential risks to human health from chronic exposure to contaminants. The HILs are referred to by regulators, auditors and consultants in the process of assessing site soil contamination.

HILs are defined as the concentration of a contaminant above which further appropriate investigation and evaluation will be required.

Levels in excess of the HILs do not imply unacceptability or that a significant health risk is likely to be present. Similarly, levels under the HILs do not necessarily imply acceptability or that a health risk is not likely to be present if sensitive sub-populations are receptors or the assumptions for land-use scenarios are not appropriate.

The HILs are designed to be used as an indicator for the requirement for a more detailed (Tier 2) risk assessment. The tiered process for risk assessment into which the HILs fit is described in detail in Schedule B4.

The HILs have been designed to be protective of the health of most people who could potentially be exposed to soil contaminants under four broad land-use categories. For people within sensitive sub-populations; for example, the immunosuppressed, those with pre-existing illness, or those with pica behaviour, the HILs may not be sufficiently protective of health and site-specific criteria or management strategies may be required.

The HILs have been developed under four broad land-use categories. To estimate potential human exposure to soil contaminants within each of these land-use categories, generic assumptions have been made about the environment, human behaviour, the physicochemical characteristics of contaminants, and the fate and transport of contaminants in soil. The HILs have been derived by comparing estimated exposures with toxicity criteria using a quantitative modelling process. The toxicity criteria for all of the contaminants addressed in this guidance are outlined in the toxicity profiles included in Appendix A.

As alluded to above, the HILs are not intended to be used as clean-up levels for contaminated sites. The decision on whether clean-up is required and, if so, to what extent, should be based on site-specific assessment. Health risk assessment is one aspect of making the decision, with other considerations such as practicality, timescale, effectiveness, cost, and durability also being important.

1.3 Interpretation and use of the HILs

1.3.1 Limitations on the use of the HILs

The information in this Schedule is designed to assist risk assessors in the application of HILs to assess the risks posed to human health by soil contaminants, in a preliminary site assessment. Critical to this judgement is whether the conceptual site model used to describe any of the generic land-use categories is representative of the site in question.

The conceptual site model for some sites may identify other potential risks from soil contamination that are not covered by the HILs including:

- alternate sources of contamination, for example, groundwater or surface water
- short-term acute health risks, such as the explosion or asphyxiation risks associated with the build-up of gases in a confined space or the skin irritation risk associated with direct dermal contact with some soil contaminants
- health risks associated with the off-site migration of contaminants, for example, the contamination of potable groundwater supplies
- health risks associated with exposure to soil contaminant vapours within a basement structure, or a structure where preferential pathways are present
- other land-use scenarios that are not adequately addressed in any of the generic land-use scenarios (e.g. agricultural land)
- risks to ecological receptors.

1.3.2 What does 'exceedance' of an HIL mean?

The potential for soil contaminant concentrations to vary significantly over a site means that a minimum number of samples are required for a representative understanding of the site. Recommendations regarding the sampling requirements for contaminated sites are outlined in Schedule B2.

Subject to the condition that site users are not identified as belonging to sensitive sub-populations, a site may be considered suitable for an intended land use provided that contaminant concentrations are less than the relevant HILs, with evidence from a sufficient number of samples and a spatially representative sampling design. In a situation where contaminant concentrations in some samples at a site exceed the HILs, statistical analysis may assist in the description and assessment of soil data in relation to the HILs.

For a site to be considered suitable for an intended land use, there are a number of statistical tests that should be adopted for the assessment of soil contamination in relation to the HILs, including:

1. The 95% upper confidence limit (UCL) of the arithmetic mean concentration of the contaminant is less than the relevant HIL value.
2. No individual sample concentration exceeds 250% of the HIL value.
3. The standard deviation of the sample concentrations does not exceed 50% of the HIL value.
4. A sufficient number of samples has been collected using a spatially representative sampling design (Schedule B2 provides advice on sampling requirements).

Guidance on how to calculate the 95% upper confidence limit and standard deviation is provided in the New South Wales sampling design guidelines (NSW DECC 1995), statistics textbooks (for example, Gilbert 1987) and US EPA guidance (US EPA 1992, 2002b).

The application of interim HILs also needs to consider soil vapour data. This data must also be analysed in order for it to be used in the appropriate exposure scenario at a site. The relevance of conducting statistical tests (other than an arithmetic mean) should be evaluated for soil vapour data. Where data is limited or it is not relevant (for the purpose of assessing exposure) to conduct statistical analysis, the maximum soil vapour concentration can be compared against the interim HIL.

Note that in applying the above guidance it is essential that the contaminant distribution is reviewed prior to applying the statistical tests and an appropriate data set selected for calculation of averages and standard deviations. This means that localised areas or volumes of significantly differing contaminant concentration ('hotspots') must be identified and removed from the data set. Hotspots may be identified using statistical tests for the identification of 'outliers' (for example, Rosner's test as described by Gilbert [1987] which assumes that the data is normally distributed which must be demonstrated – other statistical tests may be relevant for non-normally distributed data), or by judgement on the basis of analytical results and site history knowledge. Hotspots should not be ignored by 'averaging' them away, and should be assessed separately against the HILs. Identifying hotspots may require several lines of evidence, for example, statistical analysis, spatial distribution of samples and site history.

Exceedance of the HILs does not automatically imply that quantitative modelling at Tier 2 risk assessment stage is warranted. Similarly, concentrations less than that of the HILs do not necessarily imply that a Tier 2 risk assessment stage is not warranted. HILs are not intended to indicate a clear demarcation between 'acceptable' and 'unacceptable' soil contaminant levels.

The decision to proceed or not to proceed with additional data collection and risk assessment should always be considered with reference to the site-specific exposure pathways, the consequences of exposure, and the characteristics of the exposed population.

1.4 Methodology for generating the HILs

The derivation of HILs follows the same five-step process central to Australian risk assessment practice as outlined in Schedule B4 and enHealth (2011). This Schedule is structured according to this process, which is summarised below.

- *Issues identification* establishes the scope and purpose for the derivation of the HILs
- *Data collection and evaluation* entails the analysis of information about contaminants of concern and exposure pathways. Data collection for the derivation of the HILs has been carried out by literature review of Australian and international sources, and is considered according to the type of data, as part of discussion of the generic land-use scenarios, the toxicity assessment and the exposure assessment
- *Toxicity assessment* identifies the effect of the contaminants of concern on the sensitive populations and the most appropriate reference value for the quantitative assessment of dose-response. The approach adopted has been to review and utilise relevant published peer-reviewed toxicity reference values, not to undertake a comprehensive toxicity study to derive separate toxicity reference values.
- *Exposure assessment* involves the relevance and estimation of the magnitude, frequency, extent and duration of exposures to contaminants under each of the generic land-use scenarios. The general exposure assessment process applied in the derivation of the HILs is described in this Schedule, as is the process applied in estimating exposure point concentrations for volatile contaminants
- *Risk characterisation* combines the outcomes of all of the previous stages of the risk assessment into quantitative and qualitative expressions of risk and uses this information to derive risk-based HIL values
- *Uncertainty and sensitivity analysis* is a key part of the risk assessment process and was undertaken during the derivation of the HILs. It identifies the key assumptions and data gaps associated with the derivation of HILs and establishes the exposure parameters that have the greatest implications for the resultant HILs. The uncertainty and sensitivity analyses provide a 'reality check' for the HILs and are also described in this Schedule.

The HIL values are the outcomes of this risk assessment process and are presented in this Schedule.

1.4.1 Objectives

The scope and purpose for the derivation of the HILs was established during the NEPM review described above. The key objectives are:

- to produce health-based soil investigation levels suitable for use in Australian contaminated land assessments
- to produce HILs that are relevant for Australian land uses, environment, climate and population
- to produce HILs with consistent and transparent derivation
- to provide HILs for a list of priority contaminants as established by the NEPM review
- to produce HILs that are based on relevant, up-to-date, reviewed toxicological research
- to produce HILs using risk assessment methodologies that are consistent with Australian policy and best international practice.

2 Presentation of the health-based investigation levels

This chapter presents the HILs for soil contaminants. The HILs have been designed to be protective of the health of people who could potentially be exposed to soil contaminants under four broad land-use categories:

- HIL A – low density residential, including a sizeable garden
- HIL B – high density residential, not including a sizeable garden
- HIL C – developed open space or recreational areas
- HIL D – commercial industrial premises.

Further details of each of these generic land-use scenarios are provided in a later section of this Schedule. Note that 'sizeable' garden means a garden large enough to provide an area where children could play, or vegetables could be grown. A small paved back yard with flower beds but without lawn would not be a 'sizeable' garden.

2.1 Stockholm Convention

The Stockholm Convention on POPs is a global treaty to protect human health and the environment from chemicals that persist in the environment for long periods, become widely distributed geographically and accumulate in the fatty tissue of humans, domesticated food animals and wildlife. Exposure to POPs can lead to serious health effects including certain cancers, birth defects, dysfunctional immune and reproductive systems, greater susceptibility to disease, and even diminished intelligence.

The Stockholm Convention requires its parties to take measures to eliminate or reduce the release of POPs into the environment. This convention was adopted in 2001 and came into force in 2004. Australia ratified the convention in 2004.

The POPs included in the Stockholm Convention are covered by three separate annexes:

- Annex A (requiring elimination of intentional production and use) – includes aldrin, chlordane, dieldrin, endrin, heptachlor, hexachlorobenzene, mirex, toxaphene and polychlorinated biphenyls (PCBs)
- Annex B (requiring restriction) – includes DDT
- Annex C (requiring reduction/elimination of unintentional production) – includes polychlorinated dibenzo-p-dioxins and dibenzofurans (PCDD/PCDF), hexachlorobenzene and PCBs.

Under the terms of the Stockholm Treaty, a regular review process allows for additional chemicals to be nominated, and after appropriate review, included in the Treaty.

Chemicals currently nominated for addition include:

- Annex A – alpha hexachlorocyclohexane, beta hexachlorocyclohexane, chlordecone, hexabromobiphenyl, hexabromodiphenyl ether, heptabromodiphenyl ether, lindane, pentachlorobenzene, tetrabromodiphenyl ether, pentabromodiphenyl ether
- Annex B – perfluorooctane sulfonic acid, its salts and perflurooctane sulfonyl fluoride.

Further consideration of the data available for these chemicals and the potential for developing a HIL will occur in the next review of the HILs.

HILs have been developed for all of the POPs covered in the Stockholm Convention, with the exception of PCDD/PCDF, which is not included as it is rarely relevant for the assessment of contaminated sites and where it is relevant, it should be addressed on a site-specific basis.

2.2 Summary of HILs

The HIL values for the four broad land-use categories are presented in Table 2. Additional information to assist in the use of the HIL values during site-specific assessments is presented below.

2.2.1 Laboratory level of reporting

The available laboratory detection limits should be reviewed in conjunction with the HILs to ensure that the most relevant detection limit is employed and the collection of additional site-specific information (for example, soil vapour data) is appropriate.

2.2.2 Polycyclic aromatic hydrocarbons

The assessment of the health risk posed by polycyclic aromatic hydrocarbons (PAHs) is complicated by the large number of individual PAHs and the complex mixtures which exist in the environment. A specific HIL value has only been derived for the carcinogenic PAHs on the basis of benzo(a)pyrene. For other carcinogenic PAH compounds or carcinogenic PAH mixtures, the toxicity equivalence factor (TEF) approach is recommended. The TEF approach assumes that the risk posed by individual carcinogenic PAHs is additive and proportional to the potency of each compound in the mixture. The potency of individual carcinogenic PAHs is expressed relative to that for benzo(a)pyrene.

To apply the HIL to a mixture of carcinogenic PAHs, the concentration of each carcinogenic PAH in the mixture should be multiplied by the respective TEF outlined in Table 1 and the resulting values summed for comparison with the benzo(a)pyrene HIL value.

Table 1. Toxicity equivalence factors for PAHs

PAH	TEF
Benzo(a)anthracene	0.1
Benzo(a)pyrene	1
Benzo(b+j)fluoranthene	0.1
Benzo(g,h,i)perylene	0.01
Benzo(k)fluoranthene	0.1
Chrysene	0.01
Dibenz(a,h)anthracene	1
Indeno(1,2,3-cd)pyrene	0.1

Source: CCME (2008)

2.2.3 Toxicity surrogate approach

A number of the groups of chemicals addressed in the derivation of the HILs contain a number of similar chemical constituents where there is a mix of information on individual chemicals. In cases where there is insufficient information to derive separate HILs for each individual compound, the toxicity surrogate approach has been applied to the derivation of HILs for these substances. This approach involves the generation of an HIL value for a single 'indicator' chemical and the application of this information directly to the assessment of other similar chemicals within the group.

HIL values derived using the toxicity surrogate approach include cresols, DDT, aldrin and dieldrin, polychlorinated biphenyls (PCBs) and polychlorinated diphenyl ethers (PBDEs). The sum of all the individual chemical concentrations within each of these groups can be compared directly to the HIL value, under the assumption that their effects are similar and additive.

2.2.4 Inorganic mercury

The HIL value for inorganic mercury was derived using the physicochemical characteristics of mercuric mercury (Hg^{2+}). This value does not include the potential for the inhalation of vapours derived from elemental mercury. If elemental mercury is present then a site-specific assessment should be undertaken.

2.2.5 Interim HILs for volatile compounds

Investigation levels derived for the volatile chlorinated hydrocarbons are presented as interim HILs as the methodology adopted in the derivation of these values is not fully developed. The application and revision of these values will rely on improvements in the understanding of the behaviour of chlorinated solvents in transferring from soil to indoor air.

The interim HIL values derived for volatile compounds are driven by the vapour intrusion pathway. However, it is noted that there are limitations and uncertainties associated with the assessment of volatile contaminants on the basis of soil concentrations. As these limitations are significant, interim HILs for soil have not been derived. Rather it is recognised that where indoor/ambient air data cannot be collected, the most relevant approach to the assessment of this pathway is through the collection of soil vapour data. On this basis, interim HILs have been developed for soil vapour.

The values have been derived assuming a building may be directly above the contaminant source. Groundwater, if present, is assumed to be deeper than the soil source (and beneath any building foundations).

In circumstances where the building type differs (for example, inclusion of a basement), or where there is the potential for preferential vapour pathways to be present, a site-specific assessment should be undertaken.

2.2.6 Free cyanide

Cyanide impacted soils are often dominated by stable cyanide-metal complexes (for example, iron cyanide compounds) which are of low inherent toxicity and non-volatile. No HIL for complexed cyanide is presented because of the low toxicity. Free cyanide is only formed in environments that are dominated by weak cyanide-metal complexes (for example, silver cyanide) and dissolved cyanide complexes. The HIL should be compared to a free cyanide analysis, and not to a total cyanide analysis.

The presence of free cyanide in soil and the potential for formation of HCN is complex and depends on the soil pH, ionic strength and complexation. The ability of standard vapour models to estimate concentration of HCN in air (indoors and outdoors) is considered to be poor (RIVM 2001) due to the complexity of the processes involved. Hence, the HIL derived for free cyanide does not address issues that may be associated with the formation of HCN gas and potential exposures indoors and outdoors. These exposures need to be addressed on a site-specific basis.

2.2.7 Home-grown produce

Where relevant for each compound assessed, the HIL A values assume that 10% of vegetable and fruit consumption comes from produce grown on the contaminated site. Details on the potential significance of uptake into home-grown fruit and vegetable crops are presented in the chemical summaries in Appendix A.

It should be noted that consumption of home-grown eggs and poultry meat may be a significant exposure pathway for some soil contaminants and should be assessed on a case-by-case basis.

Table 2. Summary of health investigation levels for soil contaminants

Chemical	Health-Based Investigation Levels (mg/kg)			
	A	B	C[1]	D
Metals and inorganics				
arsenic[2]	100	500	300	3000
beryllium	70	100	100	500
boron	5000	40000	20000	300000
cadmium	20	140	100	800
chromium (VI)	100	500	240	3000
cobalt	100	600	300	4000
copper	7000	30000	20000	250000
lead[3]	300	1200	600	1500
manganese	3000	8000	9000	40000
methyl mercury[4]	10	30	14	200
mercury (inorganic)	200	600	400	4000
nickel	400	800	800	4000
selenium	200	1500	700	10000
zinc	8000	60000	30000	400000
cyanide (free)	250	400	350	2000
Polycyclic aromatic hydrocarbons (PAHs)				
benzo(a)pyrene TEF[5]	3	4	4	40
Total PAHs[6]	300	400	400	4000
Phenols				
phenol	3000	50000	45000	250000
pentachlorophenol	100	150	140	700
cresols	400	5500	4700	27000
Organochlorine pesticides				
DDT+DDE+DDD	260	700	400	4000
aldrin and dieldrin	7	10	9	50
chlordane	50	100	80	560
endosulfan	300	460	400	2000
endrin	10	20	20	100
heptachlor	7	10	9	50
HCB	10	20	15	85
methoxychlor	400	550	500	2700
mirex	10	20	20	100
toxaphene	20	35	30	170
Phenoxyacetic acid herbicides				
2,4,5-T	700	1000	900	5000
2,4-D	1000	2000	1400	9500
MCPA	700	1000	900	5000
MCPB	700	1000	900	5000
mecoprop	700	1000	900	5000
picloram	5000	8000	6500	37000
Other pesticides				
atrazine	360	550	500	3000
chlorpyrifos	170	400	300	2000
bifenthrin	600	900	750	4000
Other organics				
PCBs	1	2	2	8
PBDE flame retardants (Br1-Br9)	1	2	2	10

Notes:

1 - This scenario includes developed open space such as parks, playgrounds, playing fields and schools (e.g. ovals) and footpaths. This does not include undeveloped public open space which should be subject to a site-specific assessment, where appropriate.

2 - HIL for arsenic assumes 70% oral bioavailability. Site-specific bioavailability may be important and should be considered where appropriate

3 - HIL for lead based on blood lead models (IEUBK for HILs A, B and C & Adult Lead Model for HIL D) where 50% oral bioavailability has been considered. Site-specific bioavailability may be important and should be considered where appropriate.

4 - Assessment of methyl mercury should only occur where there is evidence of its potential source. Background intakes of fish may result in exceedance of the toxicity reference value without consideration of another source. In addition, the reliability and quality of sampling/analysis should be considered.

5 – HILs relevant to BaP and carcinogenic PAHs assessed on the basis of BaP TEF. Elevated levels of BaP in relatively immobile sources, such as bitumen fragments, do not represent a significant health risk.

6 – Total PAHs HILs relevant to the sum of all PAHs reported where carcinogenic PAHs meet the BaP TEF HILs and naphthalene meets the relevant HSL.

Table 3. Summary of interim health investigation levels for volatile chlorinated compounds

Chemical	Interim soil gas health investigation levels * (mg/m^3)			
	A	B	C	D
TCE	2	2	15	15
1,1,1-TCA	260	260	1800	1800
PCE	10	10	70	70
cis-1,2-dichloroethene	2	2	10	10
vinyl chloride	0.3	0.3	2	2

Notes:
* Interim soil gas HILs are soil gas concentrations that can be adopted for the purpose of screening sites where further investigation is required on a site-specific basis. They are based on the potential for vapour intrusion indoors using an indoor air to soil gas attenuation factor of 0.01 and an outdoor air attenuation factor of 0.005.

3 Generic land-use scenarios

3.1 Introduction

Assessments of potential risks to human health resulting from site contamination are based on conceptual site models (CSMs) that identify the conditions through which exposure to contaminants can occur. The key components of a CSM are the contaminant source, sensitive populations and exposure pathways.

Four generic land-use scenarios have been used to derive the HILs. These are based on the typical settings in Australia under which people may be exposed to contaminated soil. A separate set of HILs has been developed for each generic land-use category, because the sensitive populations and intensity, frequency and means of exposure to soil contaminants can differ according to land use.

The four generic land-use scenarios used in the derivation of the HILs are described below. Also in this Schedule are a description of the environment and buildings considered under each land-use scenario, a description of the characteristics of relevant sensitive human populations, and relevant exposure pathways applied under each land-use scenario. This information is designed to allow risk assessors to gauge the applicability of the HILs to the circumstances at individual sites. Details of the approaches recommended for the assessment of soil contamination at sites that are not adequately represented by any of the standard land-use scenarios are also discussed in this Schedule.

The generic land-use scenarios considered in the development of the HILs are:

- HIL A — Standard low-density residential scenario with a sizeable garden
- HIL B — Standard high-density residential scenario without a sizeable garden
- HILC — Developed open-space scenario, including parks, recreational areas and secondary school playing fields
- HIL D — Commercial/industrial scenario.

These land-use scenarios are broadly consistent with exposure settings A, D, E and F respectively, as described in enHealth (2002). When land is used for more than one purpose, the HILs that are relevant to the more sensitive land use should be adopted for that site.

3.2 Description of the generic land-use scenarios

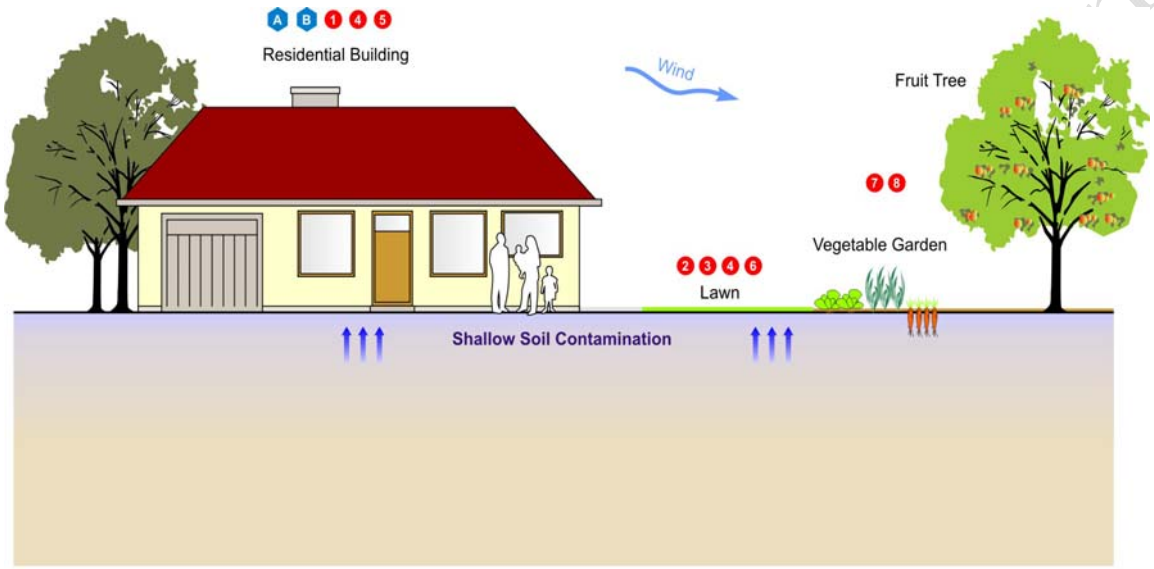
3.2.1 HIL A values - low-density residential land-use scenario with a sizeable garden

Residential land use includes a variety of building densities, ranging from separate low-density dwellings to high-density unit blocks. The residential land-use scenario considered in the derivation of the HIL A values is low-density residential, including a sizeable garden.

The HIL A values are also applicable to the preliminary assessment of potential risks at sites where children are likely to be the most sensitive human receptors, including day-care centres, kindergartens, pre-schools and primary schools. The scenario is designed to represent a typical residential land use. The HIL A values will also be protective of circumstances where less exposure to soil would be likely (for example, older people, or without fruit and vegetable gardens).

This land-use scenario assumes typical residential properties, consisting of single storey dwellings, supported by ground-level slabs. Potential health risks associated with exposure to soil contaminant vapours within a basement structure or in a house without a slab are not addressed under this land-use scenario.

These residences may have private gardens, consisting of lawns, garden beds and small vegetable gardens and areas of fruit trees, but no poultry. The occupants of the dwellings include adults, children and infants, who spend the majority of their time on the residential properties and use the outdoor areas of the residences on a frequent basis, for activities such as gardening or recreation. The CSM for this land-use scenario is provided in Figure 1.



RECEPTORS	EXPOSURE PATHWAYS	
A Adult residents B Child residents (0 - 6 years)	1 Indoor inhalation of vapours derived from shallow soil 2 Outdoor inhalation of vapours derived from shallow soil 3 Incidental ingestion of surface soil and dust particulates 4 Dermal contact with surface soil and dust particulates 5 Indoor inhalation of dust particulates	6 Outdoor inhalation of dust particulates 7 Consumption of home-grown produce 8 Consumption of soil adhering to home-grown produce

Figure 1. Conceptual site model for low-density residential land-use scenario

3.2.2 HIL B values - high-density residential scenario without a sizeable garden

The residential land-use scenario considered for the HIL B values is high-density residential, not including a sizeable private garden. This land-use scenario assumes typical residential unit blocks, consisting of multi-storey buildings supported by ground-level slabs but without underground basement structures, such as garages.

Occupants of the buildings considered in the development of the HIL B values have access to yard spaces that are largely covered by permanent paving, with some small areas of landscaping or lawns. Opportunities for direct access to soil by residents of these buildings are therefore minimal but there may be some potential for residents to inhale, ingest or come into direct dermal contact with dust (particulates) derived from the soil on the site. Landscaped/playground (including sandpit) areas used for recreation within a high-density development should be assessed on the basis of HIL C values.

The occupants of the dwellings are adults, children and infants who spend the majority of their time indoors within the residential properties, with some limited use of communal outdoor areas on site. The residents that are considered to be most susceptible to health risks associated with soil contaminants are the residents of ground floor units, due to the greatest potential for vapour intrusion occurring with residences immediately overlying contaminated soil. The CSM for this land-use scenario is provided in Figure 2.

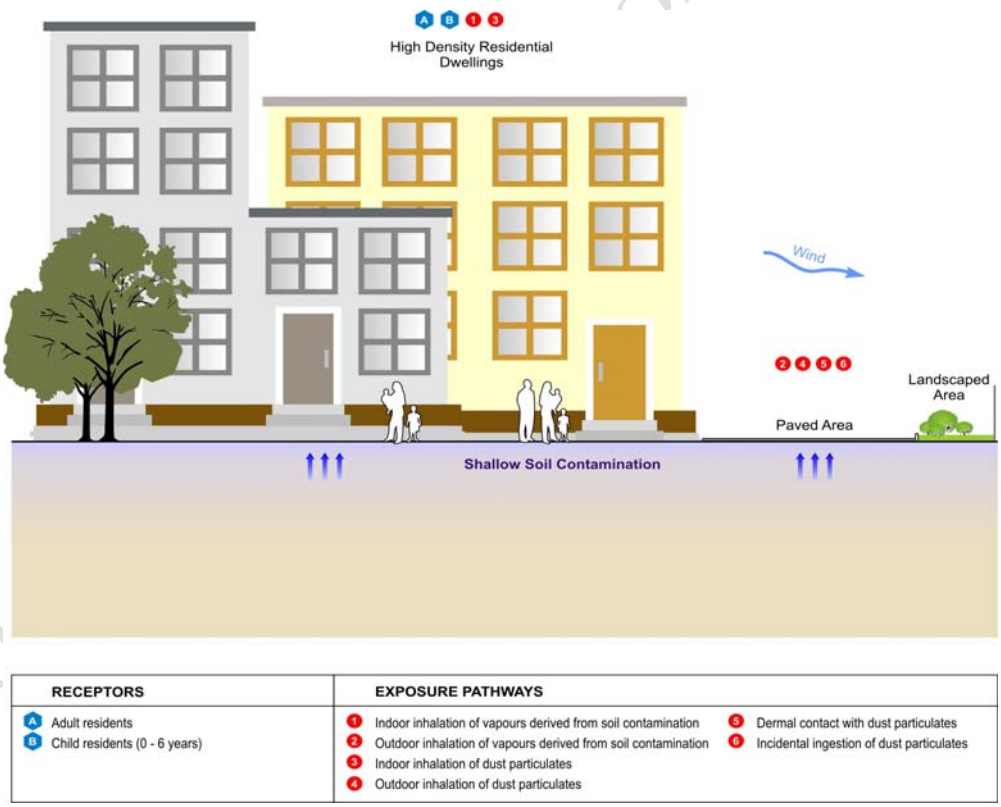
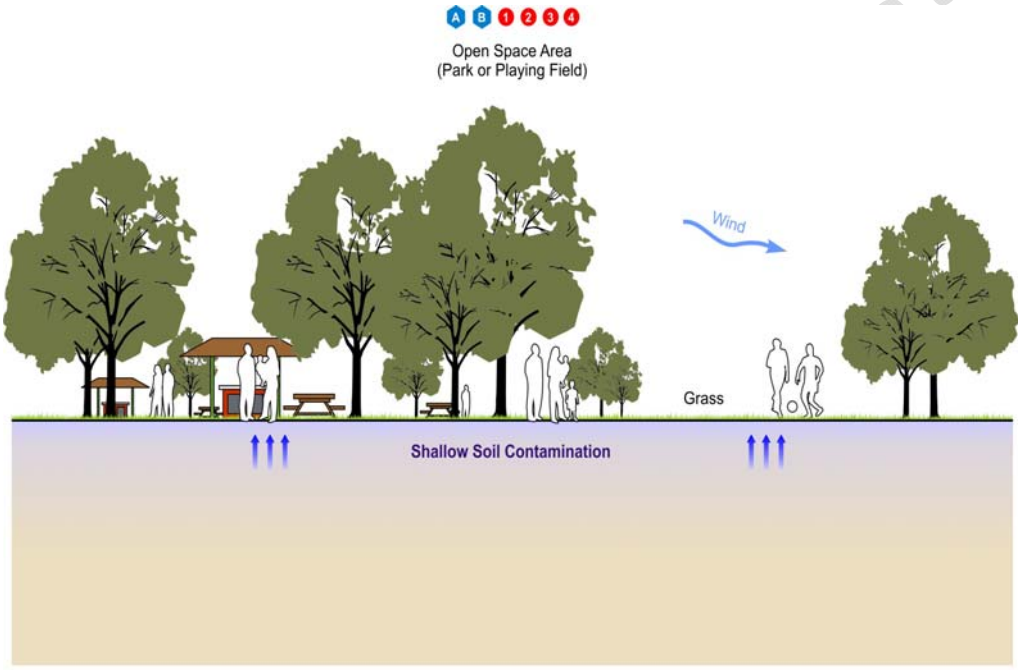


Figure 2. Conceptual site model for high-density residential land-use scenario

3.2.3 HIL C values – developed open-space scenario

Open-space land use includes a variety of exposure scenarios such as parks, playgrounds (including sandpits), recreational areas and playing fields that are fully accessible to the public and where the public may potentially spend a significant amount of time. The HIL C values are also applicable to the preliminary assessment of potential risks to the health of children using school playing fields.

This land-use scenario assumes that the open-space areas may contain lawns, gardens, vegetated areas and walkways, with some limited areas of hardstand and some areas of exposed soil. The open space areas may contain buildings such as amenity blocks, but individuals who visit these areas are considered to spend the majority of their time outdoors. The users of the open-space areas are adults and children who visit the site frequently for recreational purposes. The CSM for this land-use scenario is provided in Figure 3.



RECEPTORS	EXPOSURE PATHWAYS
A Adults recreational users B Child recreational users (0 - 6 years)	1 Outdoor inhalation of vapours derived from soil contamination 2 Outdoor inhalation of dust particulates 3 Dermal contact with soil and dust particulates 4 Incidental ingestion of soil and dust particulates

Figure 3. Conceptual site model for open-space land-use scenario

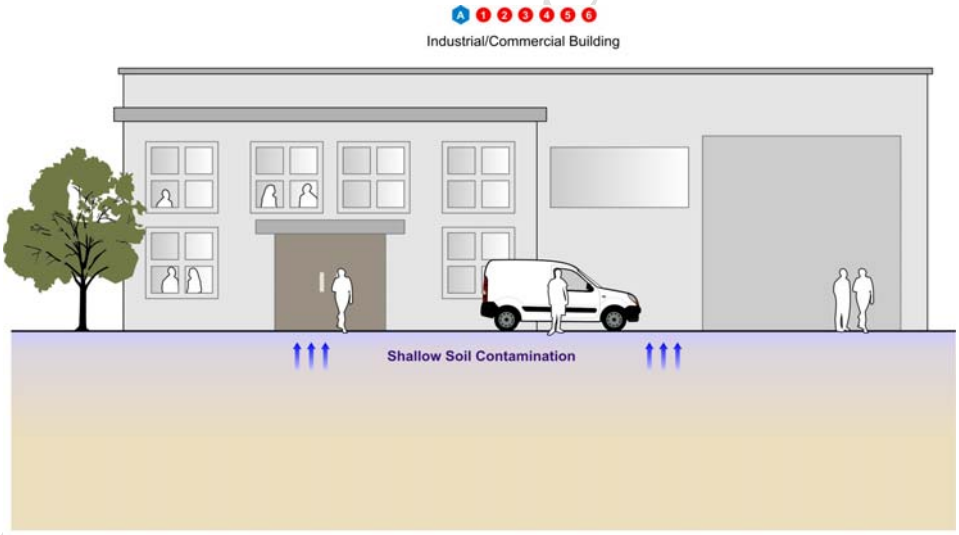
It is noted that this scenario does not directly apply to undeveloped open space which should be subject to a site-specific assessment (where appropriate).

3.2.4 HIL D values - commercial/ industrial scenario

The land-use scenario considered for the HIL D values is commercial/industrial, which assumes typical commercial or light industrial properties, consisting of single or multi-storey buildings supported by ground-level slabs. No underground basement structures, such as underground car parks, have been considered in the commercial/industrial land-use scenario.

The dominant users of commercial/industrial sites are adult employees, who are largely involved in office-based or light indoor industrial activities. The employees who are most susceptible to health risks associated with soil contaminants are the employees who work in offices on the ground floor, as the greatest potential for vapour intrusion occurs with workspaces immediately overlying contaminated soil.

The outdoor areas of the commercial/industrial facilities are largely covered by hardstand, with some limited areas of landscaping or lawns and facilities. Employees may make use of outdoor areas of a commercial/industrial premises for activities such as meal breaks. Opportunities for direct access to soil by employees using these facilities are likely to be minimal, but there may be potential for employees to inhale, ingest or come into direct dermal contact with dust particulates derived from the soil on the site. The CSM for this land-use scenario is provided in Figure 4.



RECEPTORS	EXPOSURE PATHWAYS	
A Adult employees	1 Indoor inhalation of vapours derived from soil contamination 2 Indoor inhalation of dust particulates 3 Outdoor inhalation of vapours derived from soil contamination 4 Outdoor inhalation of dust particulates	5 Dermal contact with dust particulates 6 Incidental ingestion of dust particulates

Figure 4.Conceptual site model for commercial/industrial land-use scenario

3.3 Sensitive populations

The HILs for each land-use scenario have been developed to be protective of the majority of human populations that are sensitive to potential health risks from soil contamination. The HILs depend upon both the exposure scenario and the toxicity reference values selected for the contaminant.

The level of exposure of a given human population to health risks within a particular land-use scenario is related to physiological factors (for example, children are often more heavily exposed to contaminants than adults because, in comparison to their body weight, they have higher rates of inhalation and ingestion and a larger skin surface area) and the frequency, extent and duration of exposure (for example, permanent residents are a more sensitive population than intermittent visitors).

The toxicity reference values were selected from collated peer-reviewed sources using the data sources described in Schedule B4. Unless otherwise noted, all of these sources provide criteria that represent tolerable levels of exposure to the population inclusive of those individuals considered to be sensitive to the contaminant concerned. The toxicity criteria therefore inherently incorporate protection to sensitive sub-populations. Different sources of toxicity criteria provide slightly differing approaches to protection of sensitive sub-populations because they are derived by different bodies (for example, NHMRC, WHO and US EPA) with differing policies. The source and basis of selected toxicity reference values is presented on a compound specific basis in Appendix A.

3.3.1 Residential and open-space land-use scenarios

The populations that are usually most sensitive to health risks associated with soil contamination in both low-density and high-density residential settings and in the open space scenario are young children. The characteristics of exposed populations applied in the development of the HILs have been derived in accordance with the recommendations outlined by enHealth (2011). Young child residents and recreational users are therefore considered to be aged between 0 and 6 years of age and to live within the same dwelling or visit the same open-space area for their entire childhood.

3.3.2 Commercial/industrial land-use scenario

Adults of working age are the population usually most sensitive to health risks associated with soil contamination within the generic commercial/industrial land-use scenario. Although many commercial premises welcome children on an intermittent basis, it is unlikely that children visit the majority of workplaces frequently. Similarly, in commercial premises where children are regular visitors, such as shopping centres, both the duration and frequency of child exposures are generally lower than that of a full-time adult employee.

In accordance with the recommendations outlined in enHealth (2011), the adult employees addressed in the HIL D values have been considered to work within the same commercial/industrial premises for their full working life (30 years). The HILs developed for the commercial/industrial land-use scenario are not applicable to a site used frequently by more sensitive groups such as children (within child care centres, hospitals and hotels) and the elderly (within hospitals, aged care facilities and hospices).

3.4 Exposure pathways

For each land use, consideration has been given to the ways in which people could be exposed to soil contamination. The term 'exposure pathway' is used to describe the course that a contaminant takes from its source area to reach an exposed population. An exposure pathway is considered to be 'complete' when a receptor (for example, resident or worker) receives a 'dose' of the contaminant.

For the purposes of developing the HILs, it has been assumed that exposure could potentially occur via the following exposure pathways:

- incidental ingestion of surface soil and dust
- indoor and outdoor inhalation of dust
- consumption of home-grown produce (including vegetables and fruit, but excluding poultry meat and eggs)
- consumption of soil adhering to home-grown produce
- dermal contact with surface soil and dust particulates
- indoor and outdoor inhalation of vapours derived from soil.

Not all exposure pathways are relevant to all land-use categories. For example, in the open-space scenario, it is assumed that there are no permanently occupied buildings in which indoor air could be impacted by vapours derived from the underlying soil. Hence, exposure to soil contaminants within open-space areas occurs largely in the outdoor environment and the exposure pathway of indoor vapour inhalation is not applicable. Similarly, the consumption of home-grown produce and soil adhering to home-grown produce is only applicable to the low-density residential land-use scenario.

The exposure pathways considered in the development of HILs for each of the four different land-use categories are summarised in Table 4.

Table 4. Exposure pathways considered for the four generic land-use categories

Exposure pathways	Land-use scenario			
	Low-density residential (HIL A)	High-density residential (HIL B)	Open space (HIL C)	Commercial/industrial (HIL D)
Indoor inhalation of dust	✓	✓	X	✓
Outdoor inhalation of dust	✓	✓	✓	✓
Dermal contact with shallow soil and dust	✓	✓	✓	✓
Incidental ingestion of shallow soil and dust	✓	✓	✓	✓
Ingestion of home-grown vegetables and fruit	✓	X	X	X
Ingestion of home-grown poultry and/or eggs	X	X	X	X
Ingestion of soil adhering to home-grown produce	✓	X	X	X
Indoor inhalation of vapours derived from shallow soil	✓	✓	X	✓
Outdoor inhalation of vapours derived from shallow soil	✓	✓	✓	✓

✓ - indicates exposure pathway has been considered in the derivation of the HILs
X – indicates that exposure pathway has not been considered in the derivation of the HILs

3.5 Application of the HILs to alternative land-use scenarios

The generic land-use scenarios used in the development of the HILs will be unlikely to accurately reflect all of the conditions present at an individual site. As the HILs are intended to represent a 'reasonable worst case' for each land use, provided that the site land-use is equivalent to one of the HIL scenarios, the HILs will provide for a health protective Tier 1 screening assessment. There are some limitations to the use of HILs, as described previously.

For land uses not specifically referred to in the scenario descriptions, there are two options:

- use of HIL values for an alternate (more sensitive) land-use category, as a preliminary screening tool
- the undertaking of a site-specific risk assessment.

The methodology presented in this Schedule may be used to derive 'HIL equivalent' values applicable to site-specific circumstances, by amending appropriate exposure settings and site characteristics values.

4 Toxicity assessment

The toxicity assessment component of the derivation of the HILs involved the review of the published toxicity reference values that have been developed by various published peer-reviewed government authorities and other agencies and selection of the appropriate reference value for each of the soil contaminants.

For all contaminants considered in the derivation of HILs, toxicity reference values (TRVs) have been identified following review of relevant information from published peer reviewed sources. The term TRV has been adopted as a general term that is used to define the health-based toxicity value used to derive a HIL. TRVs include both threshold and non-threshold toxicity values.

For threshold chemicals, TRVs reflect a measure of tolerable daily exposure and include values that are presented by different agencies using a range of different terms. Most commonly these include an ADI (acceptable daily intake), TDI (tolerable daily intake), TC (tolerable concentration in air), RfD (reference dose), RfC (reference concentration), MRL (minimal risk level), and REL (reference exposure level).

For non-threshold chemicals, TRVs reflect a cancer risk value commonly referred to as a cancer slope factor (CSF) or unit risk (UR).

TRVs used in the derivation of HILs are presented in Appendix A. The approach that applies to the identification of all the TRVs used in the derivation of HILs is described herein.

4.1 Sources of toxicity data

The TRVs used in the derivation of the HILs have been sourced from peer reviewed references using the data sources presented in Schedule B4.

4.2 Approach for carcinogenic contaminants

For the purpose of deriving the HILs, chemicals that are classified by the IARC as Category 1, 2A or 2B carcinogens have been considered to be carcinogenic and those classified Category 3 and 4 have been considered non-carcinogenic. There are limitations with this assumption; however, Category 3 and 4 chemicals rarely have adequate data for assessment as carcinogens. There are a number of Category 2 chemicals which also lack adequate carcinogenic dose response data and have, therefore, been assessed using non-cancer toxicity criteria; this is highlighted in the toxicity summary where relevant.

Consistent with the approach outlined in Schedule B4, the approach adopted for the assessment of carcinogens has been determined based on the mode of action. For genotoxic carcinogens, a non-threshold approach has been adopted (where data is available); however, for carcinogens that are non-genotoxic, a threshold approach has been adopted.

4.3 Toxicity approach for dermal exposure

Where specific dermal TRVs are available, these were used for the assessment of dermal contaminant toxicity; in their absence, oral TRVs have been used for the dermal hazard assessment. Oral TRVs almost invariably relate to applied dose rather than absorbed dose. Hence, the TRV has been adjusted by a gastro-intestinal absorption factor (GAF) to produce a reference value relating to absorbed dose (US EPA 2004b).

The equations applied in this adjustment are outlined as follows.

Threshold TRV_{Dermal} = Threshold TRV_{Oral} x GAF

Non-threshold TRV_{Dermal} = Non-threshold TRV_{Oral} /GAF

where

TRV_{Oral}	=	Oral toxicity reference value;
TRV_{Dermal}	=	Dermal toxicity reference value;
GAF	=	Gastrointestinal absorption factor

4.4 Background exposure and contribution of soil to total exposure

Background levels of contamination are the chemical concentrations present in the environment as a result of everyday activities (for example, emissions from motor vehicles, industry or efflux from the ground surface in the case of volatiles) or natural sources (for example, dissolution of mineral deposits). Chemicals present in food, air, water and consumer products all contribute to the quantity of the chemical which a person might be exposed to on a daily basis. The exposure from non-site sources is referred to throughout this document as 'background exposure'.

The threshold TRV is associated with a tolerable total intake from all sources, which includes food, air, water, consumer products and contamination sources. If it is known that a significant background exposure is likely to exist, then a proportion of the threshold TRV must be allocated to the background before comparing exposures derived from contamination in soil to the TRV.

This is only applied to threshold substances, because intakes of non-threshold contaminants are considered on the basis of an increase in risk, which is irrespective of background exposure (Health Canada 2004).

In the derivation of the HILs, this has been done on a chemical-specific basis by applying a factor to the threshold TRV as outlined in the equations in Appendix B. Essentially, this is calculated as follows for threshold contaminants:

$TRV_{(adjusted)}$ = (1 – Background) x TRV

The background concentration has been considered for each threshold chemical (refer to Appendix A) based on available data from Australia and, where limited data is available, from other countries. Where no data is available, an evaluation is undertaken on a chemical-specific basis with a default value for background exposure assumed where relevant.

It is possible for background exposure to be essentially negligible (contributing less than 5% of the threshold TRV) for chemicals that are not widely distributed in the environment. In these cases, 100% of the threshold TRV has been allocated to exposure from soil. This assumption should be further considered where site-specific conditions suggest otherwise.

In addition, it is also possible for background exposure to exceed the threshold TRV (for example, intakes of methyl mercury from fish), in which case a HIL cannot be derived. A few approaches are available to address this problem. In the UK (EA 2008a), when background exposure comprises greater than 50% of the threshold TRV, then the background exposure is taken to be 50% of the TRV. The New Zealand Guidance (MfE 2010) has considered the proportion allocated to exposure from soil on a case-by-case basis. In the derivation of the HILs a case-by-case approach has also been adopted.

4.5 Bioavailability and bioaccessibility

Bioavailability and bioaccessibility are discussed and defined in Schedule B4. *Bioavailability* is a measure of the rate and extent to which a substance can be absorbed by an organism once released from the soil. *Bioaccessibility* is a measure of the release of a substance from the soil into the gut or lung. Not all texts make an equivalent distinction between bioavailability and bioaccessibility, but in the assessment of contaminated soils it is a useful concept because it provides clarity on the modelling approach adopted in the derivation of the HILs.

Oral and inhalation TRVs are generally derived from direct administration of the chemical to an animal or human and as such they often intrinsically account for 'bioavailability' as defined above. TRVs represent tolerable 'uptake' or absorbed dose which is different from total 'intake'. 'Uptake' is the dose actually absorbed by the body, that is, the amount of the administered dose (or intake) that is bioavailable. Dermal TRVs are based on the oral TRV, adjusted using GAF, which represents the oral bioavailability of a substance. This is needed because the dermal dose is an 'uptake dose', since absorption through the skin occurs. The dermal bioavailability of a substance is represented by the dermal absorption factor (DAF) which describes the fraction of the substance administered to the skin that is absorbed.

TRVs rarely intrinsically account for the soil matrix bioaccessibility. Established generic values for bioaccessibility in soil are available only for lead (US EPA 2007a). Further discussion on the bioaccessibility of lead considered in the derivation of the HIL is presented in this Schedule. In addition, a bioaccessibility value for arsenic has been considered in the derivation of the HIL. For other contaminants, a bioaccessibility of 100% has been assumed in the derivation of the HILs.

It is noted that the assumptions noted above with respect to bioaccessibility are relevant to the derivation of HILs only. The conduct of any site-specific risk assessment should further consider site-specific bioaccessibility where relevant.

4.6 Speciation

A chemical 'species' is the specific form of an element defined by its oxidation (valency) state and/or complex or molecular structure. Some of these chemical species are more important for risk assessment than others. In particular, valency state and speciation are of great importance in determining the toxicity of metals and metalloids (WHO 2006a).

Cr (VI) and inorganic and organic Hg were considered as separate species in deriving the HILs, but the remainder of the HILs do not account for differences in the toxicity or bioaccessibility/bioavailability of the species of contaminants. Derivation of the HIL required assumptions to be made regarding the form of each metal in soil, and the assumptions made are detailed in the summaries in Appendix A.

4.7 Toxicity of groups of substances

A number of HILs represent groups of substances (including carcinogenic PAHs, DDT+DDE+DDD, aldrin and dieldrin, PCBs and PBDEs). Two approaches have been applied to generate a single HIL that represents several contaminants. Where this has been done, directions for application of the HIL are given. The toxicity profile for the group of substances provides details of the assumptions that are inherent in the HIL for the group.

The TEF approach involves the approximation of the properties of a group of similar substances by those of a single member of the group. The components of the mixture are assumed to contribute to the toxicity in a similar way, and their relative effect is calculated in proportion to their concentration in the mixture by adjustment using a relative potency factor. This approach has been applied in the derivation of the HIL for carcinogenic PAHs using benzo(a)pyrene as the reference substance.

The toxicity surrogate approach involves the generation of a risk level for a single 'indicator' chemical and the application of this information directly to the assessment of other similar chemicals within a group. The sum of all the chemicals in the group is compared to the HIL, assuming that their effect (if more than one of the group is present) is similar and additive. This approach is taken for cresols, PCBs, PBDEs and several groups of pesticides. The approach taken for each substance or group is described in Appendix A.

5 Exposure assessment

This chapter provides an overview of the quantitative model used in the derivation of the HILs, including a description of the model algorithms and a summary of the assumptions, including human behavioural characteristics, used in the derivation of the HILs. The information provided is designed to allow risk assessors to gauge the applicability of the HILs at individual sites.

The approach used in the derivation of the HILs is consistent with the Australian quantitative risk assessment framework, as described in Schedule B4. The calculations undertaken combine data on the toxicity of soil contaminants with estimates of potential exposure by adults and children living, working and/or playing on land affected by contamination, over a specified period. By comparing predicted exposure with toxicity reference values, HILs that are protective of human health have been derived.

The equations used to generate the HILs are presented in Appendix B. The values for all input variables used are provided either within the text, or noted in Appendix A. In general, values presented within the text are those that are considered most significant in terms of understanding the basis of the HILs. Note that input values related to the blood lead model used to derive the lead HIL are presented in Appendix C.

5.1 Exposure pathways

The exposure pathways addressed in the derivation of HILs include (refer to previously given details on which pathways are considered for each exposure scenario):

- incidental ingestion of surface soil, dust/particulates and soil adhering to home-grown produce
- indoor and outdoor inhalation of dust particulates
- consumption of home-grown produce (including vegetables and fruit, but excluding poultry meat and eggs)
- dermal contact with surface soil and dust/particulates
- indoor and outdoor inhalation of vapours derived from soil.

5.2 General human characteristics applied in the derivation of the HILs

For each standard exposure scenario, full details of the inherent human assumptions (for example, receptor characteristics and behaviour) are summarised in Table 5. In general, exposure settings were selected for consistency with guidance provided in enHealth (2011). Where enHealth guidance is not available, or when the assumption used in the derivation of the HILs differs from that provided by enHealth (2011), an additional explanation has also been provided.

5.2.1 Body weight

Average body weights of 75 kg and 15.5 kg have been selected as reasonable representations of Australian adults and children respectively, for the derivation of the HILs. These values are recommended by enHealth (2011), based on data collected in the 1995 National Nutrition Survey (ABS 1995).

The World Health Organisation drinking water guidelines are based on an average adult body weight of 60 kg (WHO 2008), but they are designed to be applicable worldwide and to cater for countries where average body weight would be much lower than that in Australia.

EnHealth (2004) recommended average adult and child body weights of 64 kg and 13.3 kg respectively, which have been widely used in Australian risk assessment. However, these figures were based on a 1975 publication by the International Commission on Radiological Protection, and are considered dated. The Australian drinking water guidelines are calculated on the basis of a 70kg average adult body weight (NHMRC 2004).

5.2.2 Exposure duration and frequency

Child exposure duration has been set at 6 years for all land-use scenarios, based on the critical child receptor age between 0-6 years. Adult residential and recreational exposure duration has been set at 24 years, reflecting a total residential exposure duration (child plus adult) of 30 years. An exposure duration of 30 years has been applied for adult commercial receptors. These exposure durations are consistent with the recommendation in enHealth (2011).

The exposure frequency applied in the residential and open-space scenarios is 365 days/year. This reflects the assumption that exposed populations are potentially using the contaminated site daily; this is a necessary assumption for residential scenarios, but is a worst-case assumption for the recreational scenario. The exposure frequency applied in the commercial/industrial land-use scenario is 240 days/year; this value assumes a 5-day working week for 48 weeks/year (enHealth 2011).

5.2.3 Averaging time

The averaging time selected depends on the type of toxic effect being assessed. The distinction between the approach for threshold and non-threshold compounds relates to the currently held scientific opinion that the mechanism of action differs for these groups (US EPA 1989).

When evaluating chronic exposures (as is the case in the derivation of HILs) to threshold toxicants, intakes are typically calculated by averaging intakes over the period of exposure (essentially the exposure duration multiplied by 365 days in a year). It is noted that the exposure duration cancels out in the exposure equations for threshold compounds.

For non-threshold toxicants, intakes are calculated by pro-rating the total cumulative dose over a lifetime. This approach for carcinogens is based on the assumption that a high dose received over a short period of time is equivalent to a corresponding low dose spread over a lifetime (US EPA 1989). The convention is almost universally to use an averaging time of a 70-year lifetime, expressed as days, resulting in an estimate of exposure as an annual average daily rate. Hence, for non-threshold contaminants, the averaging time is important.

At birth, the average male in Australia has a life expectancy of 79 years and the average female has an expectancy of 84 years (CIA 2008). In fact, according to the 2006-2008 life tables from the Australia Bureau of Statistics, 88% of females and 81% of males are still alive at age 70. By age 85, these numbers have almost been halved with 40% of males and 56% of females still alive, and these numbers drop rapidly for the next 10 years. Cancer is a disease that can take many years to form with estimates ranging from 10-20 years total. Thus, exposures in the environment that occur into old age are unlikely to have impacts on cancer rates later in life due to the rapid increase in mortality after age 85. Allowing for 10-15 years of cancer development, considering lifetime exposure to age 70 would cover the average lifespan for men and women and it would cover most exposure periods where cancers are likely to be initiated. On this basis, the averaging time of 70 years has been retained for carcinogens.

5.2.4 Inhalation rates

Adult and child residential average inhalation rates have been sourced from enHealth (2011); 16 m^3/day for adults and 10 m^3/day for children. These values are based on the mean daily inhalation rates recommended for long-term exposures by the US EPA (2009a).

For the open-space scenario, respiration rates representative of activities such as running or playing football have been applied in the derivation of the HILs. EnHealth (2011) provides estimates of 38.24 m^3/day and 30.2 m^3/day respectively for adults and children undertaking moderate intensity activities. These values are based on the mean daily inhalation rates recommended for short-term exposures by the US EPA (2009a).

The inhalation rate for the commercial/ industrial scenario has been sourced from enHealth (2011); 26.3 m^3/day for adults. This value is based on the average inhalation rate for male and female adults undertaking occupational activities, which are assumed to consist of 1/3 sitting and 2/3 light exercise.

Table 5. Exposure parameters

Parameter	Symbol	Units	HIL A Low-density residential scenario		HIL B High-density residential scenario		HIL C Open-space scenario		HIL D Commercial/industrial scenario
			Adult	Child	Adult	Child	Adult	Child	Adult
Body weight	$BW_{adult\ or\ child}$	kg	75	15.5	75	15.5	75	15.5	75
Exposure duration	$ED_{adult\ or\ child}$	years	24	6	24	6	24	6	30
Exposure frequency	EF	days	365	365	365	365	365	365	240
Soil/dust ingestion rate[1]	$IngR_{adult\ or\ child}$	mg/day	50 [2]	100 [2]	12.5[3]	25 [3]	25[4]	50[4]	25[5]
Inhalation rate	$IhalR_{adult\ or\ child}$	m^3/day	16	10	16	10	38.2	30.2	26.3
Soil/dust to skin adherence factor	SkinAdh	mg/cm^2	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Skin surface area	$SA_{adult\ or\ child}$	cm^2	20000	6100	20000	6100	20000	6100	20000
Fraction of skin exposed	F_s	%	34	38	34	38	34	38	19
Dermal absorption factor	DAF	%	Chemical specific values applied						
Time spent indoors on site each day	$Time_{in}$	hours	20	20	20	20	0	0	8
Time spent outdoors on site each day	$Time_{out}$	hours	4	4	1	1	2	2	1
Home grown fraction of vegetables consumed	HF_{veg}	%	10	10	0	0	0	0	0
Vegetable & fruit ingestion rate	VIngR	g/day	410.5	243.2	-	-	-	-	-
Averaging time for carcinogens ('lifetime')	AT_{ca}	years	70	70	70	70	70	70	70
Dust lung retention factor	LR	%	37.8	37.8	37.8	37.8	37.8	37.8	37.8

1. Soil ingestion rates for children assumes normal hand-to-mouth activity and does not account for pica behaviour
2. Soil ingestion rates for the HIL A scenario include the ingestion of soil adhering to home-grown produce
3. Soil ingestion rates for the HIL B scenario are based on the default soil ingestion rates, in which it is assumed that a quarter of the HIL A soil/dust ingestion occur.
4. Soil ingestion rates for the HIL C scenario are based on the default soil ingestion rates, in which it is assumed that half of the HIL A soil/dust ingestion occurs.
5. Soil ingestion rates for the HIL D scenario are based on the default soil ingestion rates, corrected for an 8 hr/day daily exposure duration (50% of total waking hours)

5.3 Pathway-specific exposure assumptions

This section summarises the approach and pathways-specific assumptions adopted in the derivation of the HILs. All equations relevant to the calculation of the HIL are presented in Appendix B.

5.3.1 Incidental ingestion of surface soil and dust

This exposure pathway includes the incidental ingestion of contaminated soil and dust during everyday activities. In addition, the direct consumption of soil adhering to home-grown fruit and vegetables in the low-density residential (HIL A) exposure scenario has been reviewed. Soil and dust ingestion can be an important exposure pathway for surface soil contaminants and is particularly important in the case of non-volatile chemicals, such as metals. Young children are especially vulnerable to the ingestion of soil contaminants as they may have direct contact with soil and dust during play activities.

5.3.1.1 Incidental soil/dust ingestion rate

Based on a number of overseas tracer studies, enHealth (2011) recommends a default soil ingestion rate for 0-6 year old children of 100 mg/day and a default adult soil ingestion rate of 50 mg/day and these values have been applied in the derivation of the HILs.

For HIL B (high-density residential), the ingestion rates have been multiplied by 25% to represent ingestion of indoor dust as the main ingestion exposure pathway. This assumes that residents of high-density homes do not have significant access to on-site communal play areas where ingestion of soil outdoors might be likely. If outdoor recreational/landscaped areas are present, then HIL C should be considered for these areas.

Ingestion values for HIL C are calculated assuming that 50% of the total average soil ingestion comes from outdoor soil or indoor dust as a result of being tracked indoors following use of the recreational area.

Ingestion rate for HIL D is calculated assuming that 50% of the total daily soil ingestion occurs whilst at work on the contaminated site. This allows for a nominal 16-hour waking period during which ingestion occurs (since none occurs whilst sleeping), 8 hours of which is spent at work.

The HIL assumptions do not include allowance for the small number of children and adults who deliberately eat soil, a behaviour known as 'soil pica'. Soil pica is a behaviour characterised by repeated intentional soil ingestion and people with soil-pica behaviour may ingest large quantities of soil on a regular basis. Pica behaviour is the deliberate ingestion of non-nutritive substances, such as soil, and can occur in some small children as well as some older children and adults more commonly with severe or profound intellectual disabilities. A number of studies are available that address pica behaviours; however, most of these are associated with substances/materials other than soil such as sand, clay, paint, plaster, hair, string, cloth and paper (and some others). Pica (general) behaviour (incidence) appears to be higher in lower socioeconomic groups, in rural areas, pregnant women, individuals with poor nutritional status and in children and adults with mental illness. The US EPA (2008) assumes a default soil ingestion rate of 1 g/day for children with soil pica. It is recommended that a site-specific risk assessment should be considered in situations where soil pica behaviour is likely to occur.

5.3.1.2 *Ingestion of soil adhering to home-grown produce*

The approach applied to estimate the ingestion rate of soil adhering to home-grown produce was derived from the methodology outlined by the UK Environment Agency (2009). This approach involves the application of a soil loading factor to account for the adherence of soil to home-grown produce, and a preparation factor to account for the influence of food preparation practices (for example, washing and peeling) on soil loading. The quantity of soil ingested also depends on the amount of home-grown produce consumed. Applying the current UK values to the produce consumption rates assumed relevant for Australia results in the equivalent of an additional soil ingestion rate of approximately 3 mg/day for an adult and 2 mg/day for a child, if 10 per cent of produce is grown at home. This intake is considered only minor in comparison with the soil/dust ingestion rates adopted for adults and children in HIL A, and are considered to be adequately encompassed within the level of uncertainty inherent in the ingestion rates adopted. Hence, the additional contribution of soil ingested from home-grown produce has not been considered separately in the derivation of HIL A.

Note that the contribution of soil ingested from home-grown produce may be of significance in a site-specific risk assessment where higher intakes of home-grown produce or more site-specific soil/dust ingestion rates are considered.

5.3.2 Dermal contact with surface soil and dust particulates

This exposure pathway considers the dermal uptake of chemicals following skin contact with contaminated soil and dust. Dermal exposure to contaminants is dependent on the following parameters:

- the area of exposed skin and the degree of contact with soil or dust
- the amount of soil adhering to the skin
- the amount of contaminant absorbed through the skin.

The exposure parameters specific to the dermal contact pathway are discussed in detail below.

5.3.2.1 *Area of exposed skin*

Clothing reduces dermal contact with contaminated soil. Therefore, the area of exposed skin applied in the derivation of the HILs has been based on the percentage of the skin surface area that is not covered by clothes, on average, under normal Australian circumstances.

EnHealth (2011) provides an estimate of 6 100 cm^2 for the total skin surface area of a 2-3-year-old child. An average of 38% of this area is estimated to be exposed, based on analysis of the percentage skin surface area not covered during warm weather (that is, the child is wearing shorts or skirt, a short-sleeved shirt and no socks or shoes).

The total skin surface area recommended by enHealth (2011) for adult exposure is 20 000 cm^2. In the residential and open-space scenarios, it is assumed that 34% of this area is exposed, based on typical clothing worn during gardening and yard work and outdoor recreational activities. In the commercial/industrial exposure scenario, 19% of the adult skin surface area is assumed to be exposed, which is equivalent to only the head, hands and forearms (US EPA 2009a).

5.3.2.2 *Soil/dust skin adherence*

Dermal exposure to soil contamination is highly dependent on the amount of soil that adheres to the skin following contact. Studies on soil adherence to the skin have shown that it varies according to soil type, the part of the body examined and the type of activities being undertaken when the soil is in contact with the skin; hence, the soil to skin adherence factor is a relatively uncertain parameter in any quantitative risk assessment process (US EPA 2004b). The soil to skin adherence factor applied in the generation of the HILs was 0.5 mg/cm^2, which is the default value recommended by enHealth (2011).

5.3.2.3 *Dermal absorption*

The process of absorption of chemicals through the skin is described by the DAF, which estimates the percentage of the adhered layer of soil contamination that is able to pass through the skin. The DAF considered in the derivation of the HILs is based on a review of the available data for each compound. It is noted that limited data is available for dermal absorption and hence where data is not available and dermal absorption is of potential significance default values have been adopted as follows:

- For semi-volatile organic compounds where no compound specific data is available, a default dermal absorption factor of 0.1 (10%) has been adopted consistent with US EPA Region III (US EPA 1995) and EA (2009).
- Dermal absorption of volatile organics is especially difficult to assess, because most studies have involved occluding (covering) the skin. This may give artificially high skin absorption values, since these compounds would also be expected to volatilise from the skin (MfE 2010). The US EPA Region III recommends using a dermal absorption value of 0.05% for substances with a vapour pressure similar to that of benzene (vapour pressure approximately 95.2 mm Hg). For volatiles which have vapour pressures lower than that of benzene (and where less volatilisation from the skin may occur) – a default skin absorption value of 3% is recommended (US EPA, 1995). Review of dermal absorption for benzene by EA (2009) suggests a value of 1% may be more appropriate. Given the limited data available and the relative insignificance of the dermal absorption pathway for volatile organics, a default of 3% has been assumed in the derivation of HILs.

The potential significance of dermal absorption and the DAF values adopted in the derivation of HILs are presented for each compound in Appendix A.

5.3.3 Indoor and outdoor inhalation of dust

Inhalation of dust derived from contaminated soil in both the indoor and outdoor setting has been considered in the derivation of HILs. An assessment of exposure via this pathway depends on three key factors:

1. The concentration of dust particles in indoor and outdoor air.

2. The fraction of indoor and outdoor dust particles derived from the contaminated site.

3. The rate of contaminant absorption by the lungs.

5.3.3.1 *Outdoor dust concentrations*

For the purpose of developing the HILs for scenarios A, B and D, soil-derived dust concentrations in outdoor air have been calculated using the approach proposed by Cowherd et al. (1985) and adopted by the US EPA (2002) and UK Environment Agency (2009). This approach uses a particulate emission factor (PEF), which relates the concentration of respirable dust particles (diameter <10 μm) in the air with wind speed, vegetative cover and the area of the site occupied by exposed soil. The outdoor dust concentration calculated by this means is assumed to consist of 100% site-derived soil. The value of the PEF depends upon a number of variables which are detailed in Appendix B; of most significance for the relevance of the HIL to a site is the proportion of a site area that is occupied by surface cover (for example, vegetation or hardstand), which is represented by V in Table 6.

Table 6. Proportion of surface cover (V) assumed in HIL scenarios

	HIL A standard residential	HIL B high-density residential	HIL D Commercial / industrial
Fraction of outdoor surface cover (V)	0.75	0.9	0.8

For HIL C, dust concentrations have been estimated for more open areas assuming poor ground cover and activities (such as sporting games) that involve the generation of dust. In this case, a dust in air concentration of 35 μg/m^3 (95th percentile from Australian data as presented by enHealth 2011) has been used, where 100% is assumed to be derived from the contaminated site.

5.3.3.2 *Indoor dust concentrations*

For the purpose of deriving the HILs, soil-derived dust concentrations in indoor air have been generally calculated using the approach proposed by the UK Environment Agency (2009). Indoor dust concentrations are assumed to equilibrate with outdoor dust concentrations, as described by the PEF, through natural building ventilation. In addition, indoor air is considered to be enriched with dust compared to the outdoor environment, due to the movement of dust indoors on clothing, footwear, pets, etc. and the potential for the re-suspension of dust particles in the indoor environment (Environment Agency 2009). To address this issue, the indoor dust concentration (or dust loading factor) is assumed to be equal to the 95th percentile from Australian data (enHealth 2011) which is 35 μg/m^3.

A significant proportion of house dust can be attributed to soil particles that have been tracked into the indoor environment from outdoors. EnHealth (2011) consider that 50% of the indoor dust is derived from the site soil, in accordance with the recommendations made by the US EPA (1997). This value is the 'indoor dust transport factor' (TR), and is the same for all scenarios. The TR is multiplied by an 'indoor dust loading factor' (DL) to represent the proportion of this indoor dust (which is largely on the floor) that is re-suspended into air by people moving about the building.

5.3.3.3 Dust lung retention factor

Dust particulates are characterised by enHealth (2011) according to the following particulate size distribution:

- total suspended particulates (particles 50 μm or less) - estimates inspirable dust
- PM10 (particulate matter less than 10 μm) – estimates respirable dust
- PM2.5 (particulate matter less than 2.5 μm) – estimates the respirable fraction related to health.

The dust lung retention factor describes the percentage of respirable dust that is small enough to be retained in lungs and is associated with health effects (PM2.5 fraction). For both indoor and outdoor dust exposures, the PM 2.5 fraction is estimated at 37.8% of the PM10 fraction (enHealth 2011).

5.3.4 Indoor and outdoor inhalation of vapours derived from shallow soil

This exposure pathway considers exposure to chemical vapours released from soil into indoor and outdoor air. The indoor inhalation of soil-derived vapours is often the most critical exposure pathway for volatile contaminants. Further detail on this exposure pathway is presented in this Schedule.

5.3.5 Consumption of home-grown produce

This exposure pathway considers the potential transfer of soil contamination to adults and children, through the consumption of garden vegetables and fruit grown in soils within contaminated sites. This exposure pathway has only been considered in the derivation of the HIL values for the low-density residential setting (HIL A values).

An assessment of exposure via the consumption of home-grown produce depends on these factors:

- the potential for plant uptake to be of significance (compound-specific)
- the rate of contaminant uptake by home-grown produce from the surrounding soil
- the rate of consumption of home-grown produce by those in the household
- the bioavailability of contaminants when ingested in food. This last factor is assumed to be 100% for all contaminants with the exception of lead.

The equations relevant to the assessment of intakes via the consumption of home-grown produce are included in Appendix B.

5.3.5.1 Fruit and vegetable consumption

Vegetable and fruit intakes per day have been estimated from information provided in enHealth (2011), which was derived from the *Apparent consumption of foodstuffs* (ABS 2008). A vegetable intake of 98 g/day and a fruit intake of 145 g/day were estimated for a 2-3-year-old child. The average vegetable and fruit intake for 19-65-year-old adults were estimated to be 269 g/day and 142 g/day respectively.

For the purpose of deriving the HILs, produce has been divided into four categories; green vegetables (for example, lettuce and spinach), root vegetables (for example, carrots and onions), tuber vegetables (for example, potatoes) and fruit. The percentage of vegetable consumption comprised of green, root and tuber vegetables was calculated using data provided by UK Environment Agency (2009) and is summarised in Table 7.

These percentages were applied to the consumption rates above, resulting in splitting the vegetable consumption rates into rates for the three vegetable categories. The fruit consumption rate could not be split into different kinds of fruit due to lack of data.

Table 7. Percentage of fruit and vegetable consumption comprised of separate produce groups

Produce group	Adult residents* (%)	Adult residents consumption Rate** (g/day)	Child residents* (%)	Child Resident consumption rate** (g/day)
Green vegetables	59	158.7	55	53.7
Root vegetables	18	48.4	17	16.6
Tuber vegetables	23	61.8	28	27.4
Tree fruit	100	142	100	145

* Percentage of total vegetables or fruit, from EA (2009)

** Calculated based on total vegetable and fruit intakes from Australian data (noted above)

5.3.5.2 Consumption of home-grown produce

Domestic or backyard food production is a relatively small contributor to overall food production in Australia, with the total annual home-grown fruit and vegetable crop representing 4.1% and 5.3% respectively (ABS 1995). However, a reasonably large proportion of households engage in home food production, with 35% of households producing one or more vegetable types and 36% producing one or more types of fruit (ABS 1995). Any estimate of national behaviour is likely to be somewhat misleading; in particular, the differences between urban and rural populations are likely to be significant.

An average of 10% of vegetable and fruit consumption from home-grown produce has been applied as an appropriate generic estimate for HIL A.

It is noted that the consideration of separate intakes derived for home-grown fruit and vegetable crops in addition to background dietary intakes results in some double counting of fruit and vegetable ingestion and intakes derived from these sources. This has been addressed for each contaminant where plant uptake is considered significant as noted in Appendix A.

5.3.5.3 Plant uptake factors

Perhaps the greatest uncertainty in determining uptake of a contaminant in produce is selecting the plant uptake or concentration factors (CF_y) (MfE 2010). Plants can accumulate contaminants via a number of pathways, the most important of which is typically absorption by roots where, depending on the nature of the contaminant, translocation to other portions of the plant may occur. Uptake of organic contaminants and metals occurs predominantly from the soil solution. Normally the concentration of a contaminant measured in the soil solution represents only a fraction of the total contaminant present in the soil. The ratio of the concentration in soil solution to the total in soil depends on a number of factors including soil pH, redox potential, soil organic matter, and soil texture. In soils and sediments where the clay content is relatively low, the availability of organic contaminants is strongly related to the fraction of organic carbon present (MfE 2010).

Review of plant uptake models/approaches by MfE (2010) indicated that for organics a range of simple and complex models are available. The review notes work done by EA (2006) where a number of models for the uptake of organic compounds in plants were reviewed.

A number of limitations were identified including the limited range of compounds tested (namely PAHs, PCBs and dioxins) and problems with study data (in reporting dry or fresh weight and whether data was from roots, shoots, fruits or tubers), highlighting the level of caution that should be considered in applying these models. Overall, the EA (2006) review concluded that the model performance was highly variable and all but one model over-predicted root uptake by at least an order of magnitude.

On this basis, MfE recommended to simply use CFs based on available data, and only resort to models (for organic compounds only) when measured values are not available. This approach has been adopted in the derivation of HIL A.

For metal contaminants and other inorganics (except cyanide), default values of CF_x for As, Cd Ni, Hg and Se have been derived from detailed reviews provided by the UK Environment Agency (EA 2009a, 2009b, 2009c, 2009d). The potential significance of plant uptake and the approach adopted for other metals has been addressed on a compound-specific basis in Appendix A.

For organic contaminants (where relevant), soil to plant concentration factors (CF_y) have been calculated according to the algorithms described by the UK Environment Agency (2009) and summarised in Appendix B. With the exception of the assumption regarding the fraction of soil organic carbon, assumptions about soil properties are generally the same as those used in the vapour pathway, and are described elsewhere in this Schedule. The contaminant specific physical and chemical properties are given in the relevant toxicity profile in Appendix A.

An assumption of 0.3% organic carbon has been applied to the vapour intrusion exposure pathway, as this value is consistent with the characteristics of an average sandy soil, as defined by the US EPA (2004a). An assumption of 2% organic carbon has been applied only to the calculation of CF_y values, due to likely increases in soil organic carbon levels following the long-term cultivation of home-grown produce.

5.4 Blood lead modelling

Blood lead levels are considered to be the best index of lead exposure and risk in humans. For this reason, the HILs for lead are calculated using a different approach to that for all other HILs. For the purpose of deriving the HILs, lead has been assumed to act as a threshold contaminant and a blood lead concentration of 10 µg dL^{-1} has been applied as the maximum tolerable level for adults, children and the developing fetus (NHMRC 2009). It should be noted that it is generally recognised that there may be no threshold for the neuro-toxic action of lead (DEFRA 2002).

5.4.1 Modelling adult exposures to lead

Adult exposures to lead have been estimated based upon the methodology developed by the US EPA (2003) as provided in the US EPA adult lead model. This methodology is focused on estimating blood lead concentrations in female adults exposed to lead contaminated media and the transfer of blood lead to the unborn fetus. The adult blood lead model incorporates lead exposure, uptake into the body and biokinetic transfer into the blood and developing fetus.

The adult lead intake rate (dominated by soil ingestion) is calculated. The estimated adult exposure is then converted to a blood lead concentration. The equations applied in the transfer of lead into adult blood and into the developing fetus are based on the methodology provided in US EPA (2003) and are given below.

$$PbB_{adult} = PbB_{background} + \frac{Pb_{intake} \times BKSF \times EF}{AT}$$

where

PbB_{adult}	Total adult blood lead concentration that have site exposures to soil lead (ug/dL)
AT	Averaging time (days/year)
EF	Exposure frequency (days/year)
$PbB_{background}$	Background adult blood lead concentration (ug/dL)
Pb_{intake}	Total lead uptake from all media (g/day)
BKSF	Biokinetic slope factor (ug/dL per ug/day)

This approach allows for protection of the most sensitive receptor in the adult scenario, which is an unborn child carried by a pregnant mother.

5.4.2 Modelling child exposures to lead

Child exposure to lead has been estimated using the integrated exposure uptake biokinetic model for lead in children (IEUBK model, version 1.1 Build9, released June 2009) developed by the US EPA in 2002 and described by the US EPA (1998, 2007b).

The IEUBK model comprises separate components for exposure, absorption and the biokinetic transfer of lead to all tissues of the body and calculates age-specific blood lead concentrations for children aged between 0 and 7 years. The HILs are based on the age range 1-2 years, as this age is considered to be the most sensitive as a result of lowest body weight combined with high hand-to-mouth activity and crawling.

The components of the IEUBK model can be summarised as follows:

- The exposure component estimates intake from soil, dust, water, air and food. The estimate is based on data input by the user. The model provides default estimates for circumstances where site-specific information is not available. Where Australian values are available (for example, lead concentration in drinking water, dietary lead ingestion rates) these have been adopted.
- The uptake component models the process by which the lead intake is transferred to blood plasma. The amount of lead that is taken up is controlled by the bioavailability of the lead, which can be specified separately for soil, water and food.
- The biokinetic component models the balance of lead in the body between uptake and excretion. A central estimate of blood lead concentration is output from this component.
- The variability component applies a log-normal distribution to the output of the biokinetic component using a geometric standard deviation of 1.6. This value is based on empirical studies where blood lead concentrations of young children and environmental lead concentrations were measured. It models the predicted variability likely to apply to the population.

The model contains 100 variables, of which 46 can be modified by the user. Those which cannot be modified are based on considerable research, and are detailed in the model user guide (US EPA 2007b). In calculating the HILs for lead, input variables consistent with those used for the other HILs have been applied. A full list of variables input to the model is provided in Appendix C, including important variables where the model defaults were retained.

5.4.3 Bioavailability and bioaccessibility of lead

Lead is the only substance for which adequate data are available to support an estimate of bioavailability. Because the toxicity criterion in lead modelling is a blood lead value, it represents an absorbed quantity and estimation of both bioavailability and bioaccessibility is appropriate. A single factor, labelled 'bioavailability' is used to represent both concepts.

US EPA (2007a) recommends use of 30% oral bioavailability of lead in soil for children, and 12% bioavailability of lead in soil for adults. There is also data available from Australian sites, which indicate that an oral bioavailability of at least 45% is likely (David Simon, South Australia Health, *pers comm.).*

Following review of the available data, an oral bioavailability of 50% (based on a review of data presented by IARC 2006) was used in the models used for the assessment of exposures to lead.

5.5 Vapour modelling

5.5.1 Introduction

The inhalation of vapours in the indoor and outdoor environment is an important exposure pathway for volatile and semi-volatile soil contaminants. The approach adopted for the derivation of HILs has used an attenuation factor, rather than a model, for estimating concentrations indoors and outdoors. There are a number of limitations and uncertainties associated with the use of any model in the estimation of exposure concentrations. In particular, the methodology and uncertainties associated with vapour modelling, particularly from a soil source are not fully resolved. Hence, at this stage for volatile chlorinated hydrocarbons, investigation levels have only been derived for soil vapour concentrations (where the soil vapour is the most appropriate data for the assessment of exposure) and are considered interim HILs. The further development of HILs for these compounds will rely on improvements in understanding of the behaviour of chlorinated hydrocarbons in transferring from soil and soil vapour to indoor and outdoor air.

With respect to the measurement of volatile compounds in soil vapour, readers are referred to Davis et al. (2009c) for field assessment methods for vapours.

All equations relevant to the derivation of the interim HILs for soil vapour are presented in Appendix B.

5.5.2 Indoor exposures

The interim soil vapour HILs for chlorinated compounds are dominated by the vapour migration and intrusion (to indoor air) pathway. The quantification of vapour migration from the source (or point of measurement) to the point of exposure (indoors) requires an assessment of migration (via diffusion and/or advection) through overlying soil and into a building where it mixes within the building (including mixing as the building air is exchanged with ambient air). Other processes that limit/retard the migration of vapours (such as sorption, transformation and degradation) or enhance vapour migration (such as via preferential pathways) also occur, however these have not been considered in the HILs.

The movement of soil gas into a building can be described on the basis of an attenuation factor (α) which is the ratio of the indoor air vapour concentration to the soil gas vapour concentration.

The approach adopted for the derivation of interim HILs has involved the use of an indoor air to soil gas attenuation factor (or ratio). The US EPA (2008) has summarised measured attenuation factors (based on data from 2002-2008) between indoor air and groundwater, soil gas vapour, sub-slab vapour and crawl-space vapour concentrations. It is noted that a large number of the data sets referenced by the US EPA are based on chlorinated hydrocarbon impacted sites and, hence, use of the data is considered relevant. The following figure is an extract from the report which presents these measured attenuation factors.

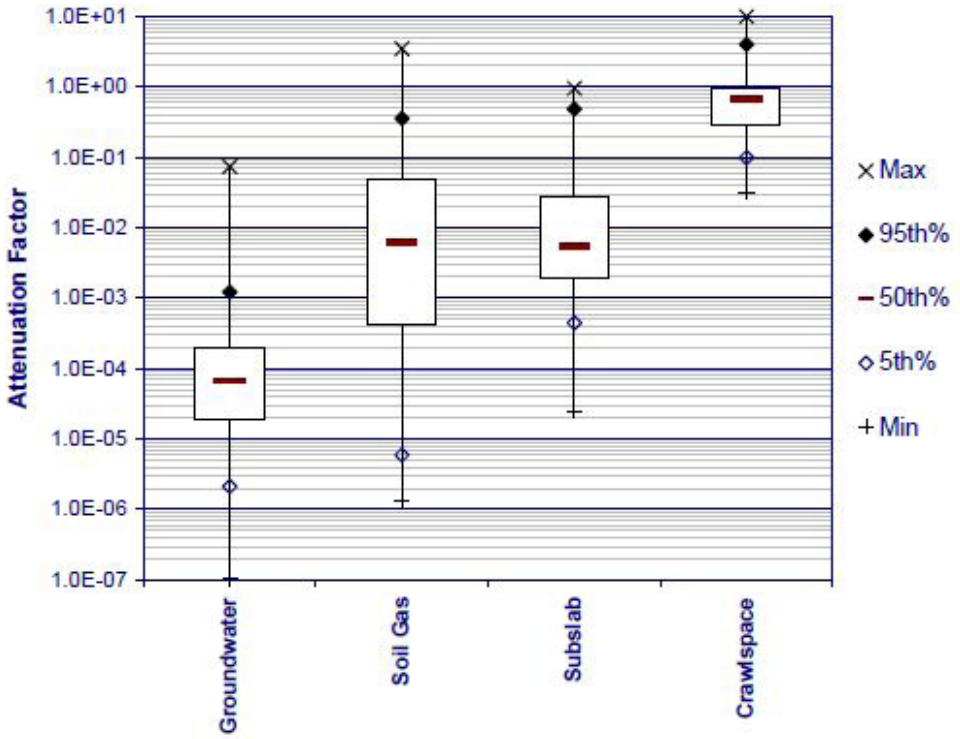


Figure 5. Summary of attenuation factor distributions for groundwater, soil gas, sub-slab, and crawlspace (ref: US EPA 2008, Figure 16)

For soil gas and sub-slab vapour attenuation factors, the measured values ranged from 1 to 0.00001, with a median value of 0.005 (US EPA 2008) and a reasonable upper value of 0.01. It is noted that there are some values that are higher than 0.01, which likely reflect contributions of indoor air sources as well as non-representative sub-slab samples at those sites (as noted by Friebel & Nadebaum 2009).

The attenuation factors have been collated across a range of soil types and building types that include both slab and basement construction and are therefore relevant for consideration in the derivation of generic HILs relevant for a wide range of sites. The use of these attenuation factors requires no further modelling of the vapour from the source (or point of measurement) to the point of exposure in indoor air.

Based on the above, a soil gas (or sub-slab) to indoor air attenuation factor 0.01, representative of the upper value not considered to be affected by indoor air sources or other factors, has been adopted in the derivation of interim HILs. Inhalation indoors is the only significant pathway of concern considered for residential A, B and commercial D scenarios. The soil gas interim HIL has been calculated on the basis of the equations presented in Appendix B, which uses exposure parameters relevant for the quantification of exposures by residents (HILs A and B) and workers (HIL D). It is recognised that adopting 0.01 as the set attenuation factor denies additional attenuation that may occur for sites with deeper sources of vapours, higher air exchange through building, or where other attenuation (including biodegradation) may occur. Consideration of these issues should be conducted in a site-specific assessment.

5.5.3 Outdoor exposures

The assessment of inhalation exposures associated with outdoor air is of most significance to the derivation of HILs for open space/recreational areas (HIL C). Limited information is available on attenuation factors relevant for outdoor air. It is noted that concentrations in outdoor air that are derived from the migration of vapours from a subsurface source are expected to be lower than those indoors due to increased dilution particularly during the daytime.

Review of average radon data suggests that outdoor air concentrations are in the order of 2 to 10 times lower than indoor air concentrations (ECA 1995). Based on this information, the more conservative ratio of indoor air to outdoor air concentrations above a subsurface source of 2 has been considered. Hence, the attenuation factor adopted for the estimation of outdoor air concentrations is 0.005 (half that of the indoor air attenuation factor).

The soil gas interim HIL C has been calculated on the basis of the equations presented in Appendix B.

As with the estimation of indoor exposures, it is recognised that adopting 0.005 as the soil vapour to outdoor air attenuation factor denies additional attenuation that may occur for sites with deeper sources of vapours, windier environments, or where other attenuation (including biodegradation) may occur. Consideration of these issues should be conducted in a site-specific assessment.

6 Risk characterisation - how the HILs were generated

6.1 The risk characterisation and calculation of HILs

Risk characterisation is the process through which the results of the exposure assessment and toxicity assessment processes are combined to provide numerical estimates of the potential risks to the identified receptors. The HILs have been calculated on the basis of the equations using a threshold or non-threshold approach (where relevant) as presented in Appendix B. The HILs have been derived assuming intakes from all pathways of exposure are additive.

6.2 Presentation of HILs

The HILs presented have been rounded to 1, and no more than 2, significant figures. This has been undertaken to reflect the level of uncertainty inherent in the range of variables used to define exposure and dose-response. Some further discussion on uncertainty is presented below.

6.3 Uncertainty and sensitivity analysis

6.3.1 HIL uncertainty analysis

The uncertainty analysis is a qualitative process that identifies the key assumptions and data gaps associated with a human health risk. Uncertainty can arise from missing or incomplete information, or arise from the scientific theory affecting the ability of a model to make predictions or result from uncertainty affecting a particular exposure or input parameter. Uncertainty has the potential to result in a cumulative overestimation or underestimation of potential health risks during an assessment.

The three broad types of uncertainty inherent in any risk assessment are:

1. *Scenario uncertainty* — uncertainty arising from missing or incomplete information such as descriptive errors, aggregation errors, errors in professional judgement and incomplete analysis.
2. *Parameter uncertainty* — uncertainty affecting a particular parameter such as measurement errors, sampling errors, variability, and use of generic or surrogate data.
3. *Model uncertainty* — uncertainties in scientific theory affecting the ability of a model to make predictions.

Scenario uncertainty in the HIL assessment is largely inapplicable, since the circumstances of the assessment are hypothetical.

There is considerable parameter uncertainty in the HIL assessment. Parameter uncertainty is usually dealt with by sensitivity analysis (see below); however, because of the generic purpose of the HILs, many parameters are set (for example, by enHealth 2011), and sensitivity analysis for these is not appropriate. The approach used to address parameter uncertainty during the derivation of the HIL values was the use of conservative or reasonable high-end exposure assumptions, allowing them to be applied across the majority of Australian sites.

Assumptions applied during the development of the HILs include:

- the use of human physical and behavioural characteristics outlined by enHealth (2011) as estimates for the Australian population

- the use of vapour attenuation factors that are not site-specific and do not account for potential degradation of either the contaminant source or migrating vapours
- the use of vegetable uptake models identified by the UK Environment Agency (2009) as being likely to overestimate potential chemical uptake by vegetable and fruit crops
- the use of toxicity criteria that are established by authoritative Australian and international public health bodies, and which are intended to be used for derivation of health protective guidelines.

The models used to estimate exposure are inherently uncertain, and are not necessarily likely to accurately predict exposure. The soil and dust ingestion, vapour inhalation, and dermal pathway approaches/models are well established and have been in use in international risk assessment for many years. Although quantitatively they are not likely to be very good predictors of exposure, they are very simple and primarily dependent on the exposure settings and toxicity criteria.

The pathways most subject to model uncertainty were the concentration of contaminants in vegetables and fruit, and the prediction of airborne dust concentrations. Uncertainty analysis was carried out by evaluating the pathways driving the HIL values (that is, percentage contributed by each) and assessing the likely reality of the proportions of exposure from each pathway. In the case of both the vegetable uptake and airborne dust pathway a number of contaminants showed unrealistic proportions of exposure. Further consideration of the model assumptions and algorithms in both cases led to the conclusion that sensitivity to input values, rather than problems with the algorithms, was the cause. The subsequent sensitivity analysis is described below.

6.4 HIL sensitivity analysis

Site-specific exposure scenarios provide the most reliable information for assessing potential human health risks. In order to allow the HIL values to be applied across a variety of Australian sites, however, generic scenarios were applied to estimate the magnitude of potential exposure during their derivation.

In sensitivity analyses, the values of parameters suspected to drive exposure risks are varied and the degree to which changes in the input variables result in changes to the risk estimates are summarised and compared (US EPA 1989). Throughout the process of deriving the HILs, sensitivity analyses were performed to provide a 'reality check' for the data adopted and to identify the key parameters influencing the resultant HIL values.

The HIL values for all of the contaminants of concern are sensitive to both the toxicity criteria and background exposure allocation applied in the risk characterisation model. Similarly, human behavioural factors such as body weight, exposure frequency and duration have a significant effect on the HIL value derived. Those assumptions set by enHealth (2011) were not varied, since these were considered policy decisions. Other exposure parameters identified as having a significant influence on the derived HIL values differ according the physicochemical characteristics of the contaminants and, in particular, the volatility of the individual chemicals. The approach taken for the key sensitive parameters is broadly summarised below.

6.4.1.1 Soil fraction of organic carbon

The vegetable ingestion pathway is highly sensitive to Foc. Friebel and Nadebaum (2009) selected a value of 0.3% for the derivation of petroleum HSLs; however, this value proved unsuitable for use with the vegetable ingestion pathway, resulting in unrealistic exposure percentages deriving from vegetables. Whilst the underlying reason for this effect is in the model formulation, increasing the Foc produced much more realistic results. Considering that it was unlikely that vegetables and fruit would really be cultivated in soils with Foc of 0.3%, a value of Foc= 2% was selected to apply to the vegetable pathway.

6.4.1.2 Vapour intrusion rate

The assessment of vapour intrusion has not been conducted using a model; rather, it is based on measured soil gas and indoor air concentrations and associated attenuation factors. The measured attenuation factors range over several orders of magnitude reflecting the wide range of sites and conditions included in the database. Indoor and outdoor air exposure concentrations are linearly related to the attenuation factor utilised. Hence, the adoption of an attenuation factor that is ten times lower will result in an indoor or outdoor air exposure concentration that is ten times lower, and an interim soil vapour HIL that is ten times higher.

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8 Glossary

Acceptable daily intake (ADI) is the estimated maximum amount of a chemical, expressed on a per kg body mass basis, to which individuals in a sub-population may be exposed daily over their lifetimes without appreciable health risk.

Acceptable risk is a risk management term. The acceptability of risk depends on scientific data, social, economic and political factors, and the perceived benefits arising from exposure to an agent.

Acute exposure is contact between an agent and a target occurring over a short time, generally 14 days or less, with a single or repeated dose. Other terms, such as 'short-term exposure' are also used.

Adverse effect is a change in the morphology, physiology, growth, development, reproduction, or life span of an organism, system, or sub-population that results in an impairment of functional capacity, an impairment of the capacity to compensate for additional stress, or an increase in susceptibility to other influences.

Aliphatic is a hydrocarbon compound that does not contain a benzene ring. Aliphatic compounds may be straight, branched or cyclic chains of carbon atoms. They may include double or triple bonds. Carbon atoms in the chain are also generally bonded to hydrogen atoms but other elements, for example, chlorine, sulphur and nitrogen can also be present.

Aromatic is a hydrocarbon containing one or more benzene rings.

Background level is the amount of agent in a medium (for example, water or soil) that is not attributed to the sources(s) under investigation in an exposure assessment. Background level(s) can be naturally occurring or the result of human activities.

Bioaccessibility is the fraction of a contaminant in soil that is soluble in the gastrointestinal tract and available for absorption.

Bioavailability is a generic term meaning the amount of a contaminant that is absorbed into the body following dermal contact, ingestion or inhalation.

Cancer is a disease of heritable, somatic mutations affecting cell growth and differentiation; that is, genetic alterations incurred in the first damaged cells are acquired in subsequent cells after cell division within the same individual.

Cancer slope factor is the plausible upper-bound estimate of the probability of a response per unit of intake of an agent over a lifetime.

Carcinogen is a cancer-causing agent.

Chemical of potential concern is an agent that is potentially site-related and whose data are of sufficient quality to be judged as potentially causing an adverse health effect.

Chronic exposure is a continuous or intermittent long-term contact between an agent and target.

Clean-up level is a concentration of contaminant in soil or water derived for the purpose of providing an acceptable standard for remediation. May be risk based or modified by

considerations of feasibility, practicality, acceptability, timescale and cost.

Concentration is the amount of material or agent dissolved or contained in unit quantity in a given medium or system.

Conceptual site model is the description of a site including the environmental setting, geological, hydrogeological and soil characteristics together with nature and distribution of contaminants. Potentially exposed populations and exposure pathways are identified. Presentation is usually graphical or tabular with accompanying explanatory text.

Contact volume is a volume containing the mass of agent that contacts the exposure surface.

Contaminant is any chemical existing in the environment above background levels and representing, or potentially representing, an adverse health or environmental risk.

Contaminated land is land that is affected by chemicals that occur at concentrations above background or local levels and which is likely to pose an immediate or long-term hazard to human health or the environment. The affected land may be within a specific site and/or adjacent off-site land.

Critical effect is the adverse effect(s) judged to be the most appropriate for determining the tolerable intake.

Data quality objectives (DQOs) describe the establishment of the amount, nature and quality of data required to complete a specific risk assessment.

Dose is the total amount of a chemical administered to, taken up by, or absorbed by an organism, system, or sub-population.

Dose-response curve is a graphical representation of a dose-response relationship.

Dose-response is the relationship between the amount of chemical administered to, taken up by, or absorbed by an organism, system, or sub-population and the change developed in that organism, system, or sub-population in reaction to the agent.

Effect is the change in the state or dynamics of an organism, system, or sub-population caused by exposure to a chemical.

Expert/professional judgement is the opinion of an authoritative person on a particular subject.

Exposed population are the people who may be exposed to the contaminant. Synonymous with 'receptor'.

Exposure assessment is the evaluation of the exposure of an organism, system, or sub-population to a chemical (and its derivatives).

Exposure is the concentration or amount of a particular chemical that reaches a target organism, or system, or sub-population in a specific frequency for a defined duration.

Exposure concentration is the exposure mass divided by the contact volume or the exposure mass divided by the mass of contact volume, depending on the medium.

Exposure duration is the length of time over which continuous or intermittent contacts occur between a chemical and the exposed population.

Exposure event is the occurrence of continuous contact between chemical and exposed population.

Exposure frequency is the number of exposure events within an exposure duration.

Exposure model is a conceptual or mathematical representation of the exposure process.

Exposure pathway is the means by which a contaminant makes contact with the exposed population.

Exposure route is the way in which an agent enters a target after contact (for example, ingestion, inhalation or dermal absorption).

Exposure scenario is a set of conditions or assumptions about sources, exposure pathways, concentration of contaminants involved, and exposed population (that is, numbers, characteristics, habits) used in the evaluation and quantification of exposure(s) in a given situation.

Genotoxic chemicals are those for which there is adequate evidence of the potential to interact with, and/or modify the function of genetic material and which have the ability to induce tumours via a mechanism involving direct damage to DNA.

Hazard identification is the identification of the type and nature of adverse effects that a contaminant has an inherent capacity to cause harm to an exposed population.

Hazard indices/index (HI) is the sum(s) of at least two hazard quotients. It is noted that the WHO is moving towards the use of risk indices/index (RI).

Hazard is the inherent property of a contaminant or situation having the potential to cause adverse effects when a population may be exposed to that contaminant.

Hazard quotient (HQ) is the ratio of the mean daily intake to the reference dose or tolerable daily intake for threshold exposure. It is noted that the WHO is moving towards the use of risk quotient (RQ).

Health investigation levels are screening criteria based on health risk, presented in this Schedule.

Intake is the total amount of contaminant (or dose) taken into the body by the exposure route.

Non-aqueous phase liquid (NAPL) is n agent that is insoluble or only slightly soluble in water that exists as a separate liquid phase in environmental media. The free liquid phase of an agent, that is not dissolved in water or adsorbed to soil.

Non-genotoxic carcinogen is an agent which induces tumours via a mechanism which does not involve direct damage to genetic material (DNA).

Pica is a behaviour exhibited occasionally by young children, characterised by the deliberate ingestion of non-nutritive substances, such as soil.

Reference dose is an estimate of the daily exposure dose that is likely to be without deleterious effect even if continued exposure occurs over a lifetime. Equivalent in meaning to tolerable daily intake and acceptable daily intake.

Remediation is the cleaning up of contaminated land.

Response is change developed in the state of dynamics of an organism, system, or sub-population in reaction to exposure to an agent.

Risk assessment is a process intended to calculate or estimate the risk to a given target organism, system, or sub-population, including the identification of attendant uncertainties, following exposure to a particular contaminant, taking into account the inherent characteristics of the agent of concern as well as the characteristics of the specific target system.

Risk characterisation is the qualitative, and wherever possible, quantitative determination, including attendant uncertainties, of the probability of occurrence of known and potential adverse effects of an agent in a given organism, system or sub-population, under defined exposure conditions.

Risk communication is an interactive exchange of information about health and environmental risks amongst risk assessors, managers, news media, interested groups, and the general public.

Risk estimation is the quantification of the probability, including attendant uncertainties, that specific adverse effects will occur in an organism, system, or sub-population due to actual or predicted exposure.

Risk evaluation is the establishment of a qualitative or quantitative relationship between risks and benefits of exposure to a chemical, involving the complex process of determining significance of the identified hazards and estimated risks to the system concerned or affected by exposure. Risk evaluation is an element of risk management. Risk evaluation is synonymous with risk-benefit evaluation.

Risk management is a decision-making process involving consideration of political, social, economic, and technical factors with relevant risk assessment information relating to a hazard to determine an appropriate course of action.

Risk is the probability of an adverse effect in an organism, system, or sub-population caused under specific circumstances by exposure to a contaminant.

Safety factor is a composite (reductive) factor by which an observed or estimated no-observed-adverse-effect-level (NOAEL) is divided to arrive at a criterion or standard that is considered safe or without appreciable risk.

Safety is the practical certainty that adverse effects will not result from exposure to an agent under defined circumstances. It is the reciprocal of risk.

Screening criteria are concentration values used in screening. Usually published for the purpose by an authoritative body (for example, HILs) or derived according to a specified methodology. Screening criteria are available for soil, groundwater, surface water and sediment.

Screening is the process of comparison of site data to screening criteria to obtain a rapid assessment of contaminants of potential concern.

Sensitive groups refers to populations with both susceptibility and vulnerability factors.

Sensitivity analysis is the process of changing one variable while leaving the others constant and determining the effect on the output. The procedure involves fixing each uncertain quantity, one at a time, at its credible lower bound and then its upper bound (holding all other at their medians), and then computing the outcomes for each combination of values (US EPA 1992). It can be used to test the effects of both uncertainty and variability in input values.

Site-specific target levels are risk-based concentration values derived using Tier 2 or Tier 3 exposure modelling. May be used as criteria for further assessment or as clean-up levels.

Source is the contaminant that is considered to represent a potential risk requiring assessment.

Sub-chronic exposure is contact between an agent and a target of intermediate duration between acute and chronic. Different bodies vary on their definitions of the duration of 'sub-chronic' exposure, since it varies with species. US EPA uses up to 10% of an organism's lifetime (enHealth 2004); however, between 3-6 months is often used when discussing sub-chronic exposure to people.

Susceptibility refers to intrinsic biological factors that can increase the health risk of an individual at a given exposure level; examples of susceptibility factors include genetic factors, late-age and early-life, prior or existing disease.

Threshold is the dose or exposure concentration of an agent below which a stated effect is not observed or expected to occur.

Tier 1 evaluation is a risk-based analysis comparing site data with generic published screening criteria for various land uses (for example, residential, commercial and industrial). This tier has the lowest data requirement, generic exposure assumptions, and applies the

most conservative criteria.

Tier 2 evaluation is a site-specific assessment in which risks to potentially exposed populations are assessed using site-specific data on pathways, land uses and the characteristics of the exposed populations. A Tier 2 evaluation usually involves the use of a quantitative exposure model. A Tier 2 evaluation is more complex than a Tier 1 evaluation and requires more site-specific information. As a result, a health protective effect will be achieved with a lower level of conservatism.

Tier 3 evaluation is a further step from a Tier 2 evaluation and looks in more detail at specific risk-driving factors. This often involves additional data collection, and may incorporate more sophisticated modelling techniques.

Tolerable daily intake (TDI) is analogous to *acceptable daily intake*. The term 'tolerable' is used for substances that are not deliberately added, such as contaminants in food and water.

Toxicity is the inherent property of a chemical to cause an adverse biological effect.

Toxicity reference value (TRV) is a measure of tolerable intake or acceptable risk, such as reference dose and cancer slope factor.

Uncertainty analysis is a methodology that takes into account domain knowledge and its limitations in qualifying or quantifying (or both) the uncertainty in the structure of a scenario, structure of a model, inputs to a model and outputs of a model.

Uncertainty is a lack or incompleteness of information or knowledge. In risk assessment, uncertainty has been defined by IPCS (2004) as 'imperfect knowledge concerning the present or future state of an organism, system, or sub-population under consideration'.

Unit risk is the plausible upper-bound estimate of the probability of a response from a chemical over a lifetime expressed in units of concentration for a specified medium.

Uptake is the amount of contaminant that enters the body through a barrier such as the skin, lungs or gut lining. Uptake is generally less than intake because not all the contaminant that enters the lungs or gut, or contacts the skin, is absorbed.

Vadose zone is the portion of the sub-surface between the water table and the ground surface, also termed the unsaturated zone. Soil pore space in the vadose zone is only partially occupied by water, which is held in place by capillary forces and adhesion to soil particles.

Variability describes true differences in attributes or values due to diversity or heterogeneity.

Vulnerability refers to human populations at higher risk due to environmental factors; examples of vulnerability factors include - age, existing or past illness, poverty and other social determinants, smoking, poor nutrition, poor sanitation, behaviour more often associated with severe or profound intellectual disability (for example, pica).

9 Shortened forms

ADI	acceptable daily intake
ANZECC	Australian and New Zealand Environment and Conservation Council
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
ATSDR	Agency for Toxic Substances and Disease Registry
ASTM	American Society for Testing and Materials
BTEX	benzene, toluene, ethylbenzene and xylenes
BMD	benchmark dose
CRC CARE	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment
CSF	cancer slope factor
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSM	conceptual site model
DAF	dermal absorption factor
DEWHA	Department of Environment, Water, Heritage and the Arts
GAF	gastrointestinal absorption factor
HI	hazard index
HIL	health investigation levels
HQ	hazard quotient
IARC	International Agency for Research on Cancer
ILCR	increased lifetime cancer risk
IRIS	Integrated Risk Information Services
LOAEL	lowest observable adverse effect level
NEPC	National Environment Protection Council
NEPM	National Environment Protection Measure
NHMRC	National Health and Medical Research Council

NOAEL	no observable adverse effect level
OCPs	organochlorine pesticides
PAHs	polycyclic aromatic hydrocarbons
PCBs	polychlorinated biphenyls
POPs	persistent organic pollutants
RfC	reference concentration
RfD	reference dose
TDI	tolerable daily intake
TPH	total petroleum hydrocarbons
TRV	toxicity reference value
UCL	upper confidence limit
URF	unit risk factor
US EPA	United States Environmental Protection Agency
WHO	World Health Organisation