



Explanatory note

The following guideline provides general guidance in relation to investigation levels for soil, soil vapour and groundwater in the assessment of site contamination.

This Schedule forms part of the National Environment Protection (Assessment of Site Contamination) Measure 1999 and should be read in conjunction with that document, which includes a policy framework and assessment of site contamination flowchart.

The original Schedule B1 to the National Environment Protection (Assessment of Site Contamination) Measure 1999 has been repealed and replaced by this document.

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Contents

Investigation levels for soil and groundwater

	Page	
1	Introduction	1
1.1	Overview	1
1.2	Prevention of site contamination	1
1.3	Specialised assessments	1
1.4	Acute hazards	1
1.5	Mineralised areas	2
2	Derivation of investigation and screening levels	3
2.1	Introduction	3
2.1.1	Definitions	3
2.1.2	Inappropriate use of investigation levels and screening levels	4
2.2	Health investigation levels	4
2.3	Interim HILs for volatile organic chlorinated compounds	5
2.4	Health screening levels for petroleum hydrocarbon compounds	6
2.4.1	Introduction	6
2.4.2	HSL methodology	6
2.4.3	Sub-slab to indoor air attenuation factor	7
2.4.4	Petroleum fuel composition	8
2.4.5	The Total Recoverable Hydrocarbons analytical method	8
2.4.6	Petroleum hydrocarbon compounds and fractions	9
2.4.7	Soil texture	9
2.4.8	Land use	10
2.4.9	Adjusting HSLs to site-specific circumstances	10
2.4.10	Biodegradation	10
2.4.11	Direct contact HSLs	11
2.4.12	HSLs and multiple-lines-of-evidence approach	11
2.4.13	Limitations of the HSLs	12
2.5	Ecological investigation levels	13
2.5.1	Introduction	13
2.5.2	EIL methodology	13
2.5.3	Land use	13
2.5.4	Levels of protection	13
2.5.5	Ecotoxicity data	13
2.5.6	Depth of application	14
2.5.7	Ambient background concentration	14
2.5.8	Added contaminant limits	14

2.5.9	Ageing of contamination and soil properties	15
2.5.10	Determining site-specific EILs	15
2.6	Ecological screening levels for petroleum hydrocarbon compounds	16
2.6.1	Introduction	16
2.6.2	ESL Methodology	16
2.6.3	Depth of application	17
2.6.4	Soil texture	17
2.6.5	Fresh and aged contamination	17
2.7	Sediment quality guidelines	17
2.8	Groundwater investigation levels	17
2.9	‘Management limits’ for petroleum hydrocarbon compounds	18
3	Application of investigation and screening levels	19
3.1	Recommended process for assessment of site contamination	19
3.2	Tier 1 assessment	19
3.2.1	Comparison with investigation and screening levels	19
3.2.2	Exceedence of Tier 1 investigation and screening levels	20
3.2.3	Procedure if no generic investigation or screening levels are available	20
3.3	Specific considerations for petroleum hydrocarbons	21
3.4	Considerations for ecological assessment	22
3.4.1	General	22
3.4.2	Scope of ecological assessment	23
3.4.3	Mobility of contaminants	23
3.5	Considerations for groundwater assessment	24
3.6	Aesthetic considerations	24
3.6.1	Introduction	24
3.6.2	Circumstances which would trigger an assessment of aesthetics	24
3.6.3	Assessment process for aesthetic issues	25
4	Asbestos materials in soil	26
4.1	Scope of the guidance	26
4.2	Historical use of asbestos in Australia	26
4.3	Work Health and Safety	26
4.4	Terminology for asbestos contamination in soil	27
4.5	Occurrence of asbestos contamination in soil	28
4.6	Asbestos soil contamination and health risk	29
4.7	Basis for health screening levels for asbestos in soil	29
4.8	Health screening levels for asbestos in soil	29
4.9	Process for assessment of asbestos contamination	30
4.10	Determining asbestos in soil concentrations	30

4.11	Assessment against asbestos screening levels and procedure for exceedences	33
5	Case Studies	35
6	Tabulated investigation and screening levels	47
7	Bibliography	75
8	Glossary	78
9	Shortened forms	81

1 Introduction

1.1 Overview

The purpose of site assessment is to determine the human health and ecological risks associated with the presence of site contamination and to inform any remediation or management plan to make the site fit for the current or proposed land use. The appropriate use of investigation levels is an integral component of the assessment process.

This Schedule provides a framework for the use of investigation and screening levels. The framework is based on a matrix of human health and ecological soil and groundwater investigation and screening levels and guidance for specific contaminants. The derivation of health-based investigation levels is outlined in Schedule B7, and the risk assessment methodologies are detailed in Schedule B4. Schedule B5a outlines a risk-based framework for site-specific ecological risk assessment. The derivation of ecological investigation levels is outlined in Schedule B5c and the methodology is detailed in Schedule B5b. Reference is also made to the derivation and use of health and ecological screening levels in site assessment.

The selection of the most appropriate investigation levels for use in a range of environmental settings and land use scenarios should consider factors including the protection of human health, ecosystems, groundwater resources and aesthetics. The development of a conceptual site model is an essential element of site assessment and should inform the selection of appropriate investigation and screening criteria. A balance between the use of generic soil, soil vapour and groundwater criteria and site-specific considerations is essential practice in site assessment.

1.2 Prevention of site contamination

The National Environment Protection (Assessment of Site Contamination) Measure 1999 (NEPM) does not provide guidance on prevention of site contamination. Owners and occupiers of sites on which potentially contaminating activities are occurring are subject to the environmental protection legislation applying in each jurisdiction. Legislation provides for appropriate controls on potentially contaminating sources, including licensing of industrial activities, to minimise emissions and its application is the principal strategy for prevention of soil and groundwater contamination.

1.3 Specialised assessments

Specialised forms of assessment are required for sites affected by the following types of contaminants:

- radioactive substances
- unexploded ordnance
- pathogenic materials and waste
- explosive gas mixtures.

In situations where these materials occur on a site under assessment, guidance should be sought from the relevant jurisdictional environmental or health authority for assessment requirements. While the general principles of site assessment are applicable to these contamination types, compliance with specialised safety protocols and assessment guidance is essential to ensure protection of human health and the environment.

1.4 Acute hazards

Risk of explosion or other acute exposure hazards should be addressed immediately and are not within the scope of this guidance document.

Health effects can be broadly separated into acute and chronic effects. The distinction between acute and chronic exposure relates to the duration of exposure and the timing of onset of any health effects.

Acute health effects occur within minutes, hours or days of a relatively short period of exposure, while chronic health effects occur as a result of prolonged or repeated exposures over many days, months or years and symptoms may not be readily apparent.

Most contaminated land assessments will be focussed on chronic health effects; however, some sites may pose acute risks. Assessment of sites with petroleum hydrocarbon contamination will need to consider the potential for acute health risks and the risk of fire and explosion from the presence of light non aqueous phase liquids (LNAPLs).

Work health and safety issues should be considered for all sites and managed according to national and jurisdictional legislative requirements.

1.5 Mineralised areas

High levels of metals, metalloids and asbestos can be associated with ore bodies. Soils in mining areas may contain elevated levels of these materials due to natural mineralisation. Some urban areas may be affected by asbestos and various elements including lead, copper, zinc, cadmium and arsenic from the ore bodies, as well as activities associated with mining, smelting and metallurgical industries.

Due to the health concerns associated with asbestos, affected areas should be effectively managed in the short and long term. Naturally occurring asbestos is most likely encountered during exploration and mining operations. Management measures similar to those for free fibre usually apply.

These environments may require specific prevention measures and community awareness programs when human settlement has occurred, to enable appropriate precautions to be taken (for example, preventing the use of potentially contaminated soil or fill from a mining site for growing vegetables in the home garden, constructing driveways or filling private land and publicly accessible areas). Public information about preventing exposure to mineralised or contaminated soil is an essential component of public health programs to minimise community exposure to these contaminants.

Depending on the nature of the contaminants associated with the mining (or quarrying) activity, contaminated soil may be only one of a number of exposure pathways. Local health issues may be more effectively targeted by monitoring key community health parameters such as blood lead or by environmental monitoring of ambient air quality and dust.

2 Derivation of investigation and screening levels

2.1 Introduction

The purpose of this Schedule is to describe soil, soil vapour and groundwater criteria that can be used to evaluate potential risks to human health and ecosystems from site contamination. Investigation and screening levels are provided for commonly encountered contaminants which are applicable to generic land use scenarios and include consideration of, where possible, the soil type and the depth of contamination.

Investigation levels and screening levels are applicable to the first stage of site assessment. The selection and use of investigation and screening levels should be considered in the context of the iterative development of a conceptual site model (CSM) (refer Schedule B2 Section 4) to ensure appropriate evaluation of human health and ecosystem risks.

Site assessment should include consideration of all relevant human exposure pathways, ecological risks and risk to groundwater resources.

2.1.1 Definitions

Investigation levels and screening levels are the concentrations of a contaminant above which further appropriate investigation and evaluation will be required.

Investigation and screening levels provide the basis of Tier 1 risk assessment. A Tier 1 assessment is a risk-based analysis comparing site data with generic investigation and screening levels for various land uses to determine the need for further assessment or development of an appropriate management strategy. The application of investigation and screening levels is subject to a range of limitations.

Ecological investigation levels (EILs) have been developed for selected metals and organic substances and are applicable for assessing risk to terrestrial ecosystems. EILs depend on specific soil physicochemical properties and land use scenarios and generally apply to the top 2 m of soil. Further detail is provided in Section 2.5 and Schedule B5.

Ecological screening levels (ESLs) have been developed for selected petroleum hydrocarbon compounds and total petroleum hydrocarbon (TPH) fractions and are applicable for assessing risk to terrestrial ecosystems. ESLs broadly apply to coarse- and fine-grained soils and various land uses. They are generally applicable to the top 2 m of soil. Further detail on their use is provided in Section 2.6 and Warne (2010a, 2010b), available from the ASC NEPM Toolbox.

Groundwater investigation levels (GILs) are the concentrations of a contaminant in groundwater above which further investigation (point of extraction) or a response (point of use) is required. GILs are based on Australian water quality guidelines and drinking water guidelines and are applicable for assessing human health risk and ecological risk from direct contact (including consumption) with groundwater. Further information is provided in Section 2.8 and Schedule B6.

Health investigation levels (HILs) have been developed for a broad range of metals and organic substances. The HILs are applicable for assessing human health risk via all relevant pathways of exposure. The HILs are generic to all soil types and apply generally to a depth of 3 m below the surface for residential use. Site-specific conditions should determine the depth to which HILs apply for other land uses. Further detail is provided in Section 2.2 and Schedules B4 and B7.

Interim soil vapour health investigation levels (interim HILs) have been developed for selected volatile organic chlorinated compounds (VOCCs) and are applicable to assessing human health risk by the inhalational pathway. They have interim status pending further scientific work on volatile gas modelling from the sub-surface to building interiors for chlorinated compounds. Further detail on their use is provided in Section 2.3 and Schedule B4.

Health screening levels (HSLs) have been developed for selected petroleum compounds and fractions and are applicable to assessing human health risk via the inhalation and direct contact pathways. The HSLs depend on specific soil physicochemical properties, land use scenarios, and the characteristics of building structures. They apply to different soil types, and depths below surface to >4 m. Further detail on their use is provided in Section 2.4 and Friebel and Nadebaum (2011a, 2011b & 2011c).

‘Petroleum hydrocarbon management limits’ (‘management limits’) are applicable to petroleum hydrocarbon compounds only. They are applicable as screening levels following evaluation of human health and ecological risks and risks to groundwater resources. They are relevant for operating sites where significant sub-surface leakage of petroleum compounds has occurred and when decommissioning industrial and commercial sites. Further detail on their use is provided in Section 2.9, including factors to be considered in determining the depth to which they apply.

2.1.2 Inappropriate use of investigation levels and screening levels

Investigation and screening levels are not clean-up or response levels nor are they desirable soil quality criteria. Investigation and screening levels are intended for assessing existing contamination and to trigger consideration of an appropriate site-specific risk-based approach or appropriate risk management options when they are exceeded. The use of these levels in regulating emissions and application of wastes to soil is inappropriate.

The use of investigation and screening levels as default remediation criteria may result in unnecessary remediation and increased development costs, unnecessary disturbance to the site and local environment, and potential waste of valuable landfill space. Similarly, the inclusion of an investigation and screening level in this guidance should not be interpreted as condoning discharges of waste up to these levels.

2.2 Health investigation levels

The health risk assessment methodology that forms the basis for calculation of HILs is provided in Schedule B4. The derivation of the HILs is presented in Schedule B7 (and appendices) and uses the *Australian exposure factor guidance* (enHealth 2012). The derivation of the HILs is illustrated by two worked examples for cadmium and benzo(a)pyrene (refer Schedule B7 Appendix B). The spreadsheet for calculating HILs is included in the ASC NEPM Toolbox (www.scew.gov.au/nepms/assessment-of-site-contamination.html).

The HILs are listed in Table 1A(1), found at the end of this Schedule.

HILs are scientifically based, generic assessment criteria designed to be used in the first stage (Tier 1 or ‘screening’) of an assessment of potential risks to human health from chronic exposure to contaminants. They are intentionally conservative and are based on a reasonable worst-case scenario for four generic land use settings:

- HIL A – residential with garden/accessible soil (home grown produce <10% fruit and vegetable intake, (no poultry), also includes children’s day care centres, preschools and primary schools
- HIL B – residential with minimal opportunities for soil access includes dwellings with fully and permanently paved yard space such as high-rise buildings and flats
- HIL C – public open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools and footpaths. It does not include undeveloped public open space (such as urban bushland and reserves) which should be subject to a site-specific assessment where appropriate
- HIL D – commercial/industrial such as shops, offices, factories and industrial sites.

The land use scenarios are described in detail in Section 3 of Schedule B7. To make generic estimates of potential human exposure to soil contaminants, scientifically based assumptions are made about the environment, human behaviour, the physicochemical characteristics of contaminants, and the fate and transport of contaminants in soil within each of these land use categories. The HILs are derived by integrating these exposure estimates with toxicity reference values, that is, tolerable daily intakes (TDI), acceptable daily intakes (ADI), and reference doses (RfD), to estimate the soil concentration of a substance that will prevent exceedence of the toxicity reference value under the defined scenario. The toxicity reference values are generally based on the known most sensitive significant toxicological effect. Where toxicity reference values come from multiple sources, their underlying assumptions, defaults and science policy should be compatible and generally similar.

HILs establish the concentration of a contaminant above which further appropriate health investigation and evaluation will be required. Levels slightly in excess of the HILs do not imply unacceptability or that a significant health risk is likely to be present. Exceeding a HIL means further investigation is required and not ‘risk is present, clean-up required’.

The HILs are referred to by regulators, auditors and consultants in the process of assessing soil contamination. HILs apply generally to the top 3 m of soil for residential use. Site-specific conditions should determine the depth to which HILs apply for other land uses.

HILs are not intended to be clean-up levels. The decision on whether clean-up is required, and to what extent, should be based on site-specific assessment triggered by an exceedence of the HIL. Health risk assessment is the primary driver for making site decisions. Other considerations such as practicality, timescale, effectiveness, cost, sustainability and associated ecological risk assessment are also relevant.

2.3 Interim HILs for volatile organic chlorinated compounds

Interim HIL soil vapour levels for specific volatile organic chlorinated compounds (VOCCs) have been developed (see Table 1A(2) at the end of this Schedule) to assess the vapour inhalation pathway (also known as the ‘vapour intrusion’ pathway when referring to indoor exposure). The derivation of the interim HILs is presented in Schedule B7 and Appendix A6. The methodology employs a simple though conservative approach using an attenuation factor that relates the concentration of a volatile contaminant in indoor air to the concentration in soil gas immediately below a building foundation slab.

The interim HIL values derived for volatile compounds are driven by the vapour intrusion pathway (that contributes >99% of the total risk when all pathways are considered). 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 for volatile organic chlorinated compounds, interim HILs for soil have not been derived. Rather it is recognised that where indoor/ambient air data cannot be collected (or the data is adversely affected by background sources), 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 interim HILs provide Tier 1 guidance for health risks from soil contamination sources and groundwater plumes associated with this group of compounds. The values may be applied for general site assessment and sub-slab environments for evaluation of potential health risks for the 0–1 m sub-slab profile. The interim HILs broadly apply to the same generic land use categories as do the HILs, though the values for residential A and B are combined as they are based on the same exposure conditions (i.e. the same amount of time spent indoors) for the vapour inhalation pathway. In addition, secondary school buildings should be treated as residential for the purposes of evaluating risks from vapour intrusion.

Biodegradation of VOCCs has not been included in the development of the interim HILs. The biodegradation approach developed for petroleum hydrocarbons (refer Section 2.4.10) is not applicable to the degradation of VOCCs as the mechanism by which degradation occurs is different for most chlorinated hydrocarbons compared with petroleum hydrocarbons.

2.4 Health screening levels for petroleum hydrocarbon compounds

2.4.1 Introduction

Site contamination by petroleum hydrocarbon compounds is frequently encountered. The complex mixtures of aliphatic and aromatic compounds that comprise petroleum hydrocarbon products present human health concerns predominantly through inhalation of vapours from contaminant sources and by direct contact with affected soils and groundwater. Assessment of petroleum impacts should include evaluation of risks via the groundwater pathway (e.g. consumption of contaminated groundwater that is not considered in the HSLs), the risk to groundwater resources and appropriate consideration of aesthetics. The application of relevant ecological and ‘management’ criteria for petroleum compounds is discussed in Sections 2.6 and 2.9.

Health Screening Levels (HSLs) for various petroleum hydrocarbon compounds were developed by the Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE). The principal reference for the HSL methodology is Friebel and Nadebaum (2011a). In addition to the documentation of the methodology, a detailed application report (Friebel & Nadebaum 2011b) and a sensitivity analysis of the main parameter inputs ((Friebel & Nadebaum 2011c) are available.

Predictive modelling of sub-surface vapour movement in soil and penetration of building structures is a field of intensive data collection and research. The most recent research and derivation approaches adopted in developed international jurisdictions have been considered and adapted, as far as is practicable, for Australian conditions, to derive Tier 1 screening criteria for evaluating human health risk from petroleum hydrocarbons.

The HSLs’ development was guided by a project advisory group with health, environmental, assessment and remediation, petroleum industry and regulatory expertise. A specialised technical working group provided technical support and review throughout the development process. The HSL methodology was subject to international peer review during its development.

Copies of the technical reports can be found in the ASC NEPM Toolbox. Additional information on the development phases of the project, including responses to peer review comments, can be found on the CRC CARE website:

http://www.crccare.com/publications/technical_reports/hsl_tech_report.html

Assessment of vapour risks is a specialist area. It is the responsibility of contaminated land professionals to become familiar with the limitations of the HSLs and their correct application in site assessment (Friebel & Nadebaum 2011a, 2011b, 2011c).

2.4.2 HSL methodology

The HSLs were developed to be protective of human health by determining the reasonable maximum exposure from site sources for a range of situations commonly encountered on contaminated sites. As there are many parameter inputs to the methodology, very conservative assumptions have not been made for every parameter as this would result in an unrealistic result arising from the compounding of conservatism. Typically the parameter values selected correspond to the mean or median of the available information, with some parameters corresponding to the 95th percentile. For further information on the rationale for each parameter selected, refer to Friebel and Nadebaum (2011a).

The HSLs apply to the same land use settings as for the interim HILs for VOCCs and include additional consideration of soil texture and depth to source to determine the appropriate soil, groundwater and soil vapour criteria for the exposure scenario. As with all modelling approaches, the assumptions made regarding the exposure scenario limit the extent of their reasonable application. The main limitations for the HSLs are summarised in Section 2.4.13.

HSLs for soil (Table 1A(3)), groundwater (Table 1A(4)) and soil vapour (Table 1A(5)) apply to exposure to petroleum hydrocarbons through the dominant vapour inhalation exposure pathway only. Direct contact HSLs have been developed for the incidental soil ingestion, dermal and inhalation exposure pathways. The direct contact HSLs are generally not the risk drivers for further site assessment for the same contamination source as the HSLs for vapour intrusion. Direct contact exposure should be considered where relevant to the site-specific scenario e.g. an external source in near-surface soils in a residential or recreational setting. Further details can be found in Friebel and Nadebaum (2011a, 2011b, and 2011c).

There are many site-specific, soil-specific and building-specific variables that affect the level of the HSLs and these factors should be considered in the site assessment. Detailed information on the model inputs and assumptions (for example, soil properties, sub-slab attenuation factor, organic carbon content, chemical properties, building parameters) and overall limitations are provided in Friebel and Nadebaum (2011a). A sensitivity analysis was used to evaluate the effect that these parameters have on the derived HSLs (Friebel & Nadebaum 2011c).

A review of vapour models was undertaken by CSIRO as a precursor project to the development of the HSLs (Davis et al. 2009c). As a result of this review, a modified Johnson and Ettinger vapour exposure model (US EPA 2004) was selected to derive HSLs for the vapour inhalation pathway. The model has been used assuming a finite source for soils equivalent to a source thickness of 2 m which avoids the extreme conservatism associated with assuming an infinite source and reflects empirical field observations. For groundwater and soil vapour, an infinite source (i.e. steady state model) has been assumed as replenishment of vapours may occur by contaminated groundwater flowing beneath the site.

It is noted that the Johnson and Ettinger model and other similar vapour intrusion models do not adequately address vapour risk issues where there are preferential vapour migration pathways, where the building structure extends into a saturated contaminated zone (i.e. into the groundwater table) or where biodegradation is of significance (see section 2.4.10 for further information).

The soil and groundwater HSLs are based on three-phase equilibrium theory and soil vapour is limited by the maximum solubility limit of the chemical in the soil pore water phase or the groundwater. The soil saturation concentration of a particular contaminant is the condition where pore water is at its solubility limit and soil vapour is at the maximum vapour concentration. When a calculated HSL in soil or groundwater exceeds this limit, the vapour in the soil or above groundwater cannot result in an unacceptable vapour risk and is denoted as NL (not limiting) in the HSL tables (Tables 1 A(3) – 1A(5)). Soil vapour HSLs are based on the vapour pressures of individual chemicals. Calculated soil vapour HSLs that exceed the possible maximums are similarly denoted as NL.

The HSLs have been derived using accepted approaches to assessment for non threshold (cancer) risk and threshold (non-cancer) risk. Exposure factors for the individual carcinogenic and non-carcinogenic compounds of concern were derived from a near-final draft of enHealth (2012).

2.4.3 Sub-slab to indoor air attenuation factor

Unlike the derivation of the soil vapour interim HILs, the attenuation factor adopted for petroleum hydrocarbon compounds is not used directly to calculate indoor air concentrations from soil gas concentrations (or vice versa); rather it is used to calculate one of the many input parameters

(advective air flow) in the Johnson & Ettinger model. For further information refer to section 7.3.2 of Friebel and Nadebaum (2011a).

As for other input parameters, the selected value for the attenuation factor is based on a reasonable assumption rather than the maximum possible exposure and is equivalent to the median of the US EPA 2008 attenuation factor database (US EPA 2008) and lies within the 75th to 95th percentiles of the updated database published in 2012 (US EPA 2012). The selected value of 0.005 was considered to represent the upper value not affected by indoor air sources, background air or other confounding factors.

2.4.4 Petroleum fuel composition

The soil saturation and water solubility limits used in the derivation of the HSLs assume a fixed fuel composition based on fresh petrol and diesel fuels typical of those available in Australia. The HSLs may be applied to other fuel types (e.g. kerosene, aviation fuel and fuel oil) providing that the aliphatic/aromatic speciation is similar to that assumed in the derivation of the HSLs (80:20). Further information on these fuel types can be found in TPHCWG (1998). There are a number of fuel additives, such as MTBE and ethanol, for which HSLs have not been derived. Where these are identified as potential contaminants of concern, then a site-specific risk assessment for these chemicals should be considered.

The HSLs apply to petroleum contamination sources and are not applicable to pure compound solvents, as solubility limits incorporated into the HSLs were derived based on typical petrol and diesel fuel mixtures. Equivalent values to the HSLs applicable to pure compounds (rather than fuel mixtures) are available in Friebel and Nadebaum (2011a Appendix C).

2.4.5 The Total Recoverable Hydrocarbons analytical method

The Total Recoverable Hydrocarbons (TRH) method is recommended for the analysis of petroleum hydrocarbon compounds in soil. Detailed information is provided in Schedule B3.

The term TRH is equivalent to the previously used total petroleum hydrocarbons (TPH) and represents extracted biogenic (biological) and petrogenic (petroleum) hydrocarbons by selected solvents. The TRH analysis is non-specific and will extract organic compounds such as ethanol, biodiesel compounds (esterised long chain fatty acids), organic acids, sterols and n-alkanes from plant waxes, as well as petroleum hydrocarbons. The sample extraction process may also extract other industrial organic chemicals. When used in the context of a screening assessment for petroleum hydrocarbon contamination, TRH analyses are likely to be conservative when non-petroleum compounds are present.

The potential for inclusion of non-petroleum compounds in the results may be relevant for site-specific assessment of petroleum hydrocarbon contamination. For example, the TRH analytical results may be overly conservative if soil organic matter is unusually high, for example from heavy applications of mulch, manure, compost or other natural organic material, or the presence of other synthetic organic compounds which are extractable in the analytical process. To assess potential false positive results, it is recommended that equivalent soil from the site, unaffected by petroleum hydrocarbon contamination, is analysed for comparison.

Where there is reasonable doubt as to the nature of the contamination, the sample may be subjected to a silica gel clean-up and analysed by gas chromatography mass spectrometry (GC-MS) (or other appropriate analytical method) to assist with the identification of contamination of petroleum origin. In these cases, an analyst report should be obtained with an interpretation of the chromatogram and the nature and extent of contamination present in the sample.

2.4.6 Petroleum hydrocarbon compounds and fractions

HSLs have been developed for BTEX and naphthalene plus four carbon chain fractions based on the fractions adopted in the *Canada-wide standard for petroleum hydrocarbons (PHC) in soil* (CCME 2008). The fractions are listed in Table 1 below:

Table 1. HSL fractions and corresponding equivalent carbon range

Fraction number	Equivalent carbon number range
F1	C ₆ - C ₁₀
F2	>C ₁₀ - C ₁₆
F3	>C ₁₆ - C ₃₄
F4	>C ₃₄ - C ₄₀

The HSLs are provided in Tables 1A(3) – 1A(5)).

BTEX results should be subtracted from the TRH C₆ – C₁₀ analytical results for comparison with the HSL for F1. Likewise, naphthalene should be subtracted from >C₁₀ – C₁₆ for comparison with the HSL for F2.

Chemicals in the >C₁₆-C₃₄ and >C₃₄-C₄₀ fractions are non-volatile and therefore not of concern for vapour intrusion, however, exposure can be via direct contact pathways (dermal contact and incidental ingestion and inhalation of soil particles). Direct contact HSLs for these fractions can be found in Friebel and Nadebaum (2011a).

2.4.7 Soil texture

HSLs for soil, groundwater and soil vapour have been developed for sand, silt and clay soils based on the US soil texture classification system (Friebel & Nadebaum 2011a). The HSLs assume a uniform soil profile and the soil texture making up the greatest proportion of the soil profile should be used in selecting the appropriate HSLs (Friebel & Nadebaum 2011a and 2011b).

For Tier 1 soil assessment, the HSL classifications of sand, silt and clay may be broadly applied to the soil texture classification in Table A1 of Standard AS 1726.

Table 2. HSL soil classification and equivalent soil classification in AS 1726

HSL soil classification	AS 1726 Equivalent
Sand	Coarse-grained soil
Silt	Fine-grained soil - silts and clays (liquid limit <50%)
Clay	Fine-grained soil - silts and clays (liquid limit >50%)

Where there is reasonable doubt as to the appropriate soil texture to select, either a conservative selection should be made (i.e. select coarsest applicable grain size such as sand) or laboratory analysis carried out to determine particle size and hence soil texture sub-class (refer Section 7.3.1 in Friebel and Nadebaum 2011b). If particle size analysis is undertaken then laboratory measurement of

additional parameters used in site-specific risk assessment (such as soil moisture content, organic carbon content and saturation porosity - refer Friebel & Nadebaum 2011b for further information) could also be considered if further assessment is possible. If laboratory measurement is undertaken, sufficient samples should be obtained and analysed to determine a representative value for each soil unit of interest for the assessment.

2.4.8 Land use

The HSLs are derived for various depths to source and for the same generic land uses as for the HILs (described in detail in Schedule B7). The values for residential A and B are combined in the HSL tables as they are based on the same exposure conditions for the vapour inhalation pathway (i.e. the same amount of time spent indoors).

The HSLs are applicable to ground floor land use. If the vapour exposure is acceptable at ground level, it can be assumed that it is also acceptable for floors above ground level. For multistorey buildings where non-residential uses (e.g. car parking or commercial use) exist in a basement or at ground level, then land use category D (commercial/industrial) should be applied.

Any sensitive land uses e.g. childcare or day care centre will require application of HSL A irrespective of their planning zoning. Secondary school buildings (as opposed to secondary school grounds) should also be assessed using HSL A.

2.4.9 Adjusting HSLs to site-specific circumstances

The HSL methodology enables parameter inputs to be changed to more accurately reflect local soil, site or building conditions. Input parameters should be selected to be representative of long-term stable conditions and appropriate to the soil unit/aquifer of concern e.g. moisture content may vary seasonally and may also be different beneath buildings. Where insufficient data is available to establish a representative value, a conservative approach should be taken, for example, by assuming dry soil moisture conditions in sand. The HSL application and sensitivity documents (Friebel & Nadebaum 2011b, 2011c) provide further details. Jurisdictions may also adopt policies to vary the HSLs to account for local conditions.

For example, air exchange rates have been set at 0.6 building volumes/hr which may not be appropriate for buildings designed for tropical and cold climates. Similarly, soil moisture has a significant effect on penetration of volatiles into buildings.

The HSL derivation has assumed a slab-on-ground construction. Elevated buildings on concrete supports or timber poles with no direct floor contact with the soil and clear underfloor ventilation are at lower risk of penetration of volatiles and the risk decreases with the elevation of the floor above ground. The state of the slab will require consideration if it has deteriorated, as cracks can act as preferential pathways.

2.4.10 Biodegradation

Recent research on underslab biodegradation of petroleum hydrocarbon contamination is reported in Davis et al. (2009a and 2009b). This research identified that the following site conditions are conducive to biodegradation of petroleum hydrocarbon compounds in the sub-surface:

- the presence of oxygen at concentrations greater than 5% in soil vapour at a depth 1 m below the surface immediately adjacent to the concrete slab

and

- a maximum slab width of less than 15 m, with oxygen access on both sides of the slab for Tier 1 screening purposes. A distance of 7–8 m from the exposed soil at the slab boundary is considered the maximum lateral underslab penetration of oxygen.

It is noted that the measurement of oxygen in the soil profile can be difficult and care should be taken when using this data to support biodegradation.

If these conditions are fulfilled, biodegradation factors can be applied to the vapour intrusion HSLs as follows:

- factor of x10 for depths to source of 2 to <4 m and
- factor of x100 for depths to source of 4 m and greater where the vapour source strength is 100 mg/L (100,000 mg/m³) or less.

The biodegradation factors above are not applicable for depths of less than 2 m. For the purpose of this NEPM, assessment including biodegradation of petroleum hydrocarbons is considered a Tier 1 activity.

Application of the biodegradation factors described above may result in levels of TPH, BTEX and naphthalene that are acceptable for human health risk from the vapour exposure pathway for the specific land use but which may not be acceptable for protection of the environment or water resources or from an aesthetics perspective. Site results should be considered with reference to relevant ecological and 'management levels' (refer Sections 2.5 and 2.9) which may become the predominant risk driver. Management levels should be applied after human health, ecological risks and risks to groundwater resources have been assessed.

2.4.11 Direct contact HSLs

Direct contact HSLs have been developed for exposure through dermal contact, incidental oral ingestion and dust inhalation and then combined as a single HSL for direct contact with soil (Friebel & Nadebaum, 2011a). For most site assessments, the direct contact HSLs are unlikely to become drivers for further investigation or site management as the values are significantly higher than most other soil screening levels and consequently have not been included here. There are situations where the combined vapour and direct contact pathways can make a difference to the outcome of the assessment. For further information on considering combined vapour and direct contact exposure, refer to Section 3.3 of Friebel and Nadebaum (2011b). The combined HSLs for direct contact can be found in Appendix A of Friebel & Nadebaum (2011a).

Contamination at the levels of the direct contact HSLs are likely to present unacceptable aesthetic considerations which should be addressed in accordance with the discussion in Section 3.6. Exposure to a contaminated surface (other than of short and temporary duration) at the levels of the direct contact HSLs may also cause an unacceptable short-term vapour exposure risk.

2.4.12 HSLs and multiple-lines-of-evidence approach

For an assessor to conclude that the vapour intrusion/emission pathways are unlikely to be active or to present a significant risk, the assessor should undertake a multiple-lines-of-evidence approach. This requires the assessor to present several reasoned lines of evidence as to why the pathway is considered inactive or is unlikely to present a significant risk.

The soil and groundwater HSLs provide the principal assessment criteria for open excavations (such as tank removal operations) while greater emphasis is placed on soil vapour HSLs in assessing potential vapour intrusion risks from hydrocarbon sources and groundwater plumes adjacent to or under buildings. In general, evaluating all contaminant phases will provide greater confidence in the outcomes of the site assessment.

Soil vapour measurements can provide a more accurate representation of vapour risks (compared with the soil and groundwater HSLs), depending on site-specific conditions e.g. where soil vapour can be measured directly under conditions that are relevant to the future or continuing use of the site. In high moisture conditions, however, such as occur within the capillary fringe or as a result of seasonal watertable fluctuations, it is not possible to obtain reliable soil vapour readings. In these conditions, consideration may be given to obtaining vapour headspace readings from appropriately constructed

groundwater monitoring wells fitted with a soil vapour monitoring cap that seals the groundwater well from the atmosphere.

Soil vapour measurements are also preferred where contaminated groundwater is present at less than 2 m below the ground or basement foundation, though in fine-grained soils the ability to obtain soil vapour measurements may be constrained by moisture conditions, as the thickness of the capillary fringe increases as the soil texture decreases.

Where the watertable rises seasonally to intersect basements or building foundations, indoor air measurements will be required to assess vapour risk. The assessment approach may also include soil vapour measurements taken in the dry season as part of a multiple-lines-of-evidence approach.

Additional information on vapour assessment and the multiple-lines-of-evidence approach is provided in Section 9.2 of Schedule B2 and Friebel and Nadebaum (2011a, 2011b).

2.4.13 Limitations of the HSLs

As with all generic screening levels, actual site-specific conditions may mean that the assumptions underpinning the derivation of the screening levels are not valid for the site and consequently a site-specific assessment will be required. The principal limitations applicable to the HSLs are listed in Table 3 below, together with suggested alternative assessment approaches.

Immediate action should be taken where potentially explosive or acutely toxic gas concentrations are present in buildings or in-ground services (e.g. utility trenches, sumps or drains) connecting a vapour source to a building. Emergency management actions, such as relocation of building occupants, should be implemented as necessary.

Table 3. Site scenarios where the application of the HSLs is limited and possible alternative assessment approaches

Site scenario	Alternative assessment approach
The identified contamination has an atypical petroleum composition	Site-specific risk assessment including assessment of cumulative effects of chemical constituents
Contaminated groundwater or LNAPL is entering or is in contact with a basement or building foundation	Consider indoor air sampling
Depth to groundwater impact is less than 2 m	Consider soil vapour measurements for vapour intrusion
The impacted soil source thickness is significantly greater than 2 m	HSLs may be conservative for thinner soil sources. For thicker soil sources, refer to Section 2.4.7 of the HSLs application document (Friebel & Nadebaum 2011b)
A preferential migration pathway is present that could connect a vapour source to a building interior	Site-specific assessment
Hydrocarbon odour present in buildings or in-ground services (not attributable to an indoor or ambient source) which indicates an active preferential migration pathway and potentially an immediate human health risk	Consider indoor air sampling or immediate action in the case of strong hydrocarbon odours

2.5 Ecological investigation levels

2.5.1 Introduction

Ecological investigation levels (EILs) for the protection of terrestrial ecosystems have been derived for common contaminants in soil based on a species sensitivity distribution (SSD) model developed for Australian conditions. EILs have been derived for As, Cu, CrIII, DDT, naphthalene, Ni, Pb and Zn.

Schedule B5a provides detailed guidance on the framework for ecological risk assessment. The methodology for deriving EILs is described in Schedule B5b and the detailed derivations of EILs for As, Cu, CrIII, DDT, naphthalene, Ni, Pb and Zn are presented in Schedule B5c. A spreadsheet, which may be used for calculating site-specific EILs is included in the ASC NEPM Toolbox.

2.5.2 EIL methodology

The detailed methodology, incorporated in Schedule B5b, was developed by CSIRO using data from various Australasian databases, the Australian National Biosolids Research Program and supplemented by data from the US EPA ecotoxicology database where necessary. The methodology is based on an SSD approach, which considers the physicochemical properties of soil and contaminants and the capacity of the local ecosystem to accommodate increases in contaminant levels (referred to as the 'added contaminant limit' or ACL) above ambient background. Where insufficient data is available for the SSD method to be used, a more conservative method using an assessment factor approach may be adopted.

The EILs are derived for specified levels of percentage species protection depending on land use. The approach is analogous to the methodology used for derivation of the Australian water quality guidelines (ANZECC & ARMCANZ 2000).

2.5.3 Land use

EILs have been developed for three generic land use settings:

- areas of ecological significance
- urban residential areas and public open space
- commercial and industrial land uses.

An area of ecological significance is one where the planning provisions or land use designation is for the primary intention of conserving and protecting the natural environment. This would include national parks, state parks, wilderness areas and designated conservation areas.

Urban residential/public open space is broadly equivalent to the HIL A, HIL B and HIL C land use scenarios (see Section 2.2 and Schedule B7).

EILs are not applicable to agricultural soils, which need evaluation in relation to crop toxicity, plant contaminant uptake and detailed consideration of soil type.

2.5.4 Levels of protection

The protection levels for the generic land use settings are:

- 99% for areas of ecological significance
- 80% for urban residential areas and public open space
- 60% for commercial and industrial land uses.

These protection levels are increased by 5% when biomagnification may occur (refer Schedule B5b).

2.5.5 Ecotoxicity data

The NEPM has adopted lowest observed effect concentration (LOEC) or effective concentration 30% (EC₃₀) data to derive EILs for the land use scenarios.

The LOEC is the lowest concentration used in a toxicity test that causes a toxic effect that is significantly different from the control. EC₃₀ data is the concentrations of contaminants that cause an effect on 30% of the test group of an organism after a specified exposure time. The data is drawn from a range of species to derive individual EILs.

For further information see Schedule B5b.

2.5.6 Depth of application

EILs apply principally to contaminants in the top 2 m of soil at the finished surface/ground level which corresponds to the root zone and habitation zone of many species. In arid regions, where the predominant species may have greater root penetration, specific considerations may result in their application to 3 m depth.

2.5.7 Ambient background concentration

The methodology assumes that the ecosystem is adapted to the ambient background concentration (ABC) for the locality and that it is only adding contaminants over and above this background concentration which has an adverse effect on the environment.

The ABC of a contaminant is the soil concentration in a specified locality that is the sum of the naturally occurring background level and the contaminant levels that have been introduced from diffuse or non-point sources by general anthropogenic activity not attributed to industrial, commercial, or agricultural activities, for example, motor vehicle emissions. Methods to estimate background levels are provided in Schedule B5b.

Three methods for determining the ABC are presented in Schedule B5b. The preferred method is to measure the ABC at an appropriate reference site. This approach is essential in areas where there is a high naturally occurring background level such as will occur in mineralised areas.

In other situations where an appropriate reference site cannot be determined, the method based on urban metal levels in Olszowy et al. (1995) or the method from Hamon et al. (2004) may be used.

In the method of Hamon et al. (2004), the ABC varies (depending on the element) with the soil iron and/or manganese concentration; for example, the ABC for zinc varies from 3 to 62mg/kg in soils with soil iron concentrations between 0.1% and 20%. Alternatively, ABCs for old and new suburbs and high and low traffic areas for New South Wales, Queensland, South Australia and Victoria for Zn, Cu, Ni, Pb, and CrIII are included in Schedule B5b and are derived from Olszowy et al. (1995). Values for new suburbs would be appropriate to use for new suburbs or in areas with no known history of contamination for that metal. In old-established urban areas (i.e. suburbs more than 20 years old), it would be appropriate to use the 25th percentile of the ABC values from Olszowy et al. (1995).

In some situations the ABC may be comparatively low and have a minor effect on the magnitude of the site EIL.

2.5.8 Added contaminant limits

An added contaminant limit (ACL) is the added concentration (above the ABC) of a contaminant above which further appropriate investigation and evaluation of the impact on ecological values is required. The EIL is derived by summing the ACL and the ABC.

ACLs are based on the soil characteristics of pH, CEC and clay content. Empirical relationships that can model the effect of these soil properties on toxicity are used to develop soil-specific values. These soil-specific values take into account the biological availability of the element in various soils. In this

approach different soils will have different contaminant EILs rather than a single generic EIL for each contaminant.

ACLs apply to chromium III (CrIII), copper (Cu), nickel (Ni) and zinc (Zn) for site-specific EIL determination. The soil properties to be determined for each relevant soil type at the site, are shown in Table 4 below.

Table 4: Soil properties to be measured for site-specific derivation of ACLs for CrIII, Cu, Ni and Zn

Soil physicochemical property	CrIII	Cu	Ni	Zn
pH		✓		
CEC		✓	✓	✓
% clay	✓			

Insufficient data was available to derive ACLs for arsenic (As), DDT, lead (Pb) and naphthalene. As a result, the derived EILs are generic to all soils and are presented as total soil contaminant concentrations in Tables 1B(4) and 1B(5).

2.5.9 Ageing of contamination and soil properties

In general the toxicity of soil contaminants (both organic and inorganic) will reduce or age over time to a lower and more stable level by binding to various soil components and decreasing their biological availability. Hence, toxicity can be affected by the physicochemical or chemical properties of the soil including clay content, cation exchange capacity (CEC) measured in centi-mole charge/kg (cmol_c/kg), pH, iron and organic carbon content.

For the purposes of EIL derivation, a contaminant incorporated in soil for at least two years is considered to be aged for the purpose of EIL derivation. The majority of contaminated sites are likely to be affected by aged contamination. Fresh contamination is usually associated with current industrial activity and chemical spills.

In some cases insufficient data on aged contamination was available to apply the EIL methodology, and where possible, ageing factors based on relevant studies have been applied to determine a soil value for aged contamination.

EIL determination for fresh contamination (that is, present for less than two years) for the relevant contaminants should be site-specifically determined by reference to the relevant tables in Schedule B5c.

2.5.10 Determining site-specific EILs

Detailed information on the derivation of the EILs is provided in Schedule B5c. The following section describes the steps that are taken to derive site-specific EILs. A spreadsheet is included in the ASC NEPM Toolbox which can also be used for calculating site-specific EILs.

A. EILs for Ni, Cr III, Cu, Zn and Pb aged contamination (>2 years)

Steps 1–4 below describe the process for deriving site-specific EILs for the above elements using Tables 1B(1) – 1B(4), which can be found at the end of this Schedule.

1. Measure or analyse the soil properties relevant to the potential contaminant of concern (see Table 4). Sufficient samples need to be taken for these determinations to obtain representative values for each soil type in which the contaminant occurs.

2. Establish the sample ACL for the appropriate land use and with consideration of the soil-specific pH, clay content or CEC. The ACL for Cu may be determined by pH or CEC and the lower of the determined values should be selected for EIL calculation. Note that the ACL for Pb is taken directly from Table 1(B)4.
3. Calculate the contaminant ABC in soil for the particular contaminant and location from a suitable reference site measurement or other appropriate method.
4. Calculate the EIL by summing the ACL and ABC:

$$\text{EIL} = \text{ABC} + \text{ACL}$$

B. EILs for As, DDT and naphthalene

EILs for aged contamination for DDT and naphthalene are not available and the adopted EIL is based on fresh contamination taken directly from Table 1B(5). The EILs for As, DDT and naphthalene are generic i.e. they are not dependent on soil type and are taken directly from Table 1B(5). Only EILs for fresh contamination are available for As, DDT and naphthalene due to the absence of suitable data for aged contaminants.

2.6 Ecological screening levels for petroleum hydrocarbon compounds

2.6.1 Introduction

Ecological screening levels (ESLs) are presented based on a review of Canadian guidance for petroleum hydrocarbons in soil and application of the Australian methodology (Schedule B5b) to derive Tier 1 ESLs for BTEX, benzo(a)pyrene and F1 and F2 (Warne 2010a, 2010b).

The Canadian Council of the Ministers of the Environment (CCME) has adopted risk-based TPH standards for human health and ecological aspects for various land uses in the *Canada-wide standard for petroleum hydrocarbons (PHC) in soil* (CCME 2008) (CWS PHC). The standards established soil values including ecologically based criteria for sites affected by TPH contamination for coarse- and fine-grained soil types.

The standard applies to the same four fractions (F1–F4) adopted for the HSLs (refer Section 2.4.5 of this Schedule).

2.6.2 ESL Methodology

The CWS PHC approach uses an SSD method and, when there is insufficient data for the SSD method, applies a weight-of-evidence approach to derive ecologically based 'Tier 1 eco soil contact' values for TPH fractions and specific compounds. The overall approach has similarities to the Australian EIL methodology by developing protective criteria based on EC₂₅ toxicity for residential land use and EC₅₀ for commercial/industrial land (cf. Australia EC₃₀ and LOEC data).

The Australian EIL methodology was applied to the ecotoxicity data used to derive the Canadian F1 and F2 (eco soil contact) values (Warne 2010a) to produce comparable Tier 1 values for these fractions. Based on the data quality and applicability to the Australian environment, the derived values for F1 and F2 are adopted as moderate reliability ESLs (see Table 1B(6) at the end of this Schedule) and apply generically to fine- and coarse-grained soils.

Due to the limited ecotoxicity data for F3 and F4, the Australian methodology was not able to be applied. The data limitations were recognised in the Canadian guidance and an alternative weight-of-evidence approach was used to develop values for these fractions. Consequently, the adopted values for F3 and F4 (see Table 1B(6)) are considered low reliability ESLs for fine- and coarse-grained soils (Warne 2010a, 2010b).

A further review of Canadian soil quality guidelines was undertaken for BTEX and benzo(a)pyrene (Warne 2010b) and the Australian methodology applied to the ecotoxicological data as far as possible to derive equivalent ESLs. However, data limitations did not allow the full use of the EIL derivation methodology and the resulting values are adopted as low reliability ESLs in Table 1B(6). Values were derived using the Canadian data reduction methods, the Australian SSD method and employing the Australian levels of protection for various land uses.

ESLs for the adopted carbon fraction ranges are based on TRH analysis with F1 being obtained after subtraction of BTEX.

2.6.3 Depth of application

ESLs apply from the surface to 2 m depth below finished surface/ground level, which corresponds to the root zone and habitation zone of many species. In arid regions, where the predominant species may have greater root penetration, specific considerations may result in their application to 3 m depth.

2.6.4 Soil texture

The ESLs are applicable to coarse and fine textured soils equivalent to coarse-grained soils and fine-grained soils in Table A1 of Standard AS 1726:1993. Conservative Tier 1 values (i.e. values for coarse soils) should be applied where site-specific textural information is not available.

2.6.5 Fresh and aged contamination

ESLs were derived on the basis of fresh contamination. GC-MS analysis and examination of the gas chromatogram output can assist in differentiating between fresh and aged TPH contamination.

While aged contamination is generally of less human health and environmental concern, sub-surface conditions can preserve some petroleum hydrocarbons for extended periods of time. Consideration should be given to the realistic risk of material being excavated and causing an exposure risk.

2.7 Sediment quality guidelines

Investigation and screening levels developed for soils should not be applied directly to the assessment of sediments.

Interim sediment quality guidelines (ISQG) are available in the *Australian and New Zealand guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANZ 2000) for a number of common metal, metalloid and organometallic contaminants and organics, principally PAHs and organochlorine pesticides (OCPs). The ISQG have limitations relating to the availability of appropriate ecotoxicology data and the small number of species on which they are based.

Reference to these guidelines, balanced by consideration of their limitations, may have application in the site-specific assessment of sites where contamination may impact aquatic receptors. Guidance on the sampling of sediments can be found in AS/NZS 5667.12:1999 *Guidance on sampling of bottom sediments* and Simpson et al. (2005).

2.8 Groundwater investigation levels

Site assessment should consider the risks from contaminated groundwater to all potential receptors on and off the site of origin and potential effects on groundwater resources.

The Groundwater investigation levels (GILs) are based on the *Australian Water Quality Guidelines 2000* (AWQG), *Australian Drinking Water Guidelines 2011* (ADWG) and *Guidelines for Managing Risk in Recreational Waters 2008* (GMRRW). The GILs are adopted in the NEPM as investigation levels in the context of the framework for risk-based assessment of groundwater contamination (refer Schedule B6) i.e. levels above which further assessment is required.

The AWQG provide tabulated values based on percentage species protection for various aquatic environments and water uses. The appropriate settings for current and potential uses of groundwater need to be identified for the aquifer undergoing assessment. The guideline documents should be consulted for appropriate interpretation of guideline values, in consultation with relevant regulatory authorities if necessary.

Table 5. Groundwater environmental values and guidelines for their protection

Environmental value to be protected	Guidelines to apply
Raw drinking water source	ADWG
Agricultural use – stock watering	AWQG
Agricultural use – irrigation	AWQG
Fresh water aquatic ecosystem	AWQG
Marine water aquatic ecosystem	AWQG
Recreational use	GMRRW

The GILs provided in Table 1C at the end of this Schedule, define acceptable water quality for various contaminants at the point of use. Table 1C provides frequently used values for drinking water and protection of fresh and marine ecosystems. Additional GILs applicable to industrial use (aquaculture), agricultural use (stock watering and irrigation) and recreational waters are provided in the referenced documents.

The GMRRW recommend applying a multiplication factor of 10 to 20 to the ADWG for assessment of the acceptability of recreational water quality. GILs for other receptors should be obtained directly from the ‘primary industries’ section of the AWQG where relevant. Note that the recreational and aesthetics sections of the AWQG have been superseded by the GMRRW.

2.9 ‘Management limits’ for petroleum hydrocarbon compounds

In addition to appropriate consideration and application of the HSLs and ESLs, there are a number of policy considerations which reflect the nature and properties of petroleum hydrocarbons:

- formation of observable light non-aqueous phase liquids (LNAPL),
- fire and explosive hazards and
- effects on buried infrastructure e.g. penetration of, or damage to, in-ground services by hydrocarbons.

The CWS PHC includes ‘management limits’ to avoid or minimise these potential effects and these values have been adopted as interim Tier 1 guidance. The values are included in Table 1B(7) at the end of this Schedule. A site-specific assessment (Tier 2 or 3) may be preferred where relevant site-specific information is available.

Application of the management limits will require consideration of site-specific factors such as the depth of building basements and services and depth to groundwater, to determine the maximum depth to which the limits should apply. The management limits may have less relevance at operating industrial sites (including mine sites) which have no or limited sensitive receptors in the area of potential impact. When the management limits are exceeded, further site-specific assessment and management may enable any identified risk to be addressed.

The presence of site TPH contamination at the levels of the management limits does not imply that there is no need for administrative notification or controls in accordance with jurisdiction requirements.

Further information on the consideration of aesthetics with respect to petroleum hydrocarbons is included in Section 3.6.

3 Application of investigation and screening levels

3.1 Recommended process for assessment of site contamination

The recommended site assessment process is shown in Schedule A of the NEPM. Refer to Schedule B2 for guidance on site characterisation.

Before comparing site data with investigation and screening levels, it is important that sufficient and appropriate characterisation of the site is carried out to ensure that the comparison is both meaningful and relevant for assessing potential risks to human health and the environment.

A number of cases studies which illustrate the application of the investigation and screening levels in site assessment are included in Section 5 of this Schedule.

3.2 Tier 1 assessment

A Tier 1 (or screening level) assessment comprises a comparison of representative site data with generic investigation levels and/or screening levels for protection of human health and the environment, together with an assessment of any limitations on their use in relation to site-specific conditions. A Tier 1 assessment provides an initial screening of the data to determine whether further assessment is required.

Contaminated sites may contain multiple contaminants in soil and groundwater and the risk posed is affected by site characteristics such as soil properties and the depth to the contamination. The selection of the appropriate investigation and screening levels to apply at a particular site should be determined using professional judgement and with reference to the CSM.

3.2.1 Comparison with investigation and screening levels

No single summary statistic will fully characterise a site and appropriate consideration of relevant statistical measurements should be used in the data evaluation process and iterative development of the CSM (refer to Schedule B2, Section 4).

The preferred approach is to examine a range of summary statistics including the contaminant range, median, arithmetic/geometric mean, standard deviation and 95% upper confidence limit (UCL). Further information is provided in Section 11 of Schedule B2.

At the very least, the maximum and the 95% UCL of the arithmetic mean contaminant concentration should be compared to the relevant Tier 1 screening criteria. However, where there is sufficient data available, and it is appropriate for the exposure being evaluated, the arithmetic mean (or geometric mean in cases where the data is log normally distributed) should also be compared to the relevant Tier 1 investigation or screening level. The implications of localised elevated values (hotspots) should also be considered. The results should also meet the following criteria:

- the standard deviation of the results should be less than 50% of the relevant investigation or screening level, and
- no single value should exceed 250% of the relevant investigation or screening level.

The maximum observed contaminant concentration generally provides a conservative assessment of exposure because if estimated risks from the maximum concentrations are not of concern, then the site should be suitable for use under the CSM considered. However, a maximum concentration may not be representative of the source as a whole and may result in an overestimation or underestimation of risk if the data is extremely limited.

The mean contaminant concentration can be a suitable metric provided that it can be shown that it adequately represents the source being considered. It is important that small areas of high concentrations or hot-spots are not ignored by averaging with lower values from other parts of the site.

The mean value may be more representative of the source as a whole than the maximum, and may provide a better estimation of the actual concentration that a population would be exposed to over a period of time.

The 95% UCL of the arithmetic mean provides a 95% confidence level that the true population mean will be less than, or equal to, this value. The 95% UCL is a useful mechanism to account for uncertainty in whether the data set is large enough for the mean to provide a reliable measure of central tendency. Note that small data sets result in higher values for the 95% UCL. Further guidance on the use of 95% UCLs can be found in NSW DECC (2006), US EPA (2006b) and US EPA (2007a).

Groundwater data being used to assess exposure should consider a relevant average at the site or off-site (as appropriate based on the CSM) together with a reasonable maximum based on understanding of seasonal and other trends in groundwater quality. Where trends are poorly defined in the early stages of an investigation, greater weight should be placed on the maximum concentration.

If air data or soil vapour data is available for the site, then the use of that data needs to be considered within the context of the CSM and the activities at the site or adjacent to the site that may affect the presence of substances in the air, including confounding substances. Consideration of both a reasonable maximum and a relevant average case should be considered where possible.

The effects of applying a multiplication factor to account for biodegradation to soil, soil vapour and groundwater HSLs where relevant should be considered in the data analysis. The data should be evaluated for trends and the presence of hot spots prior to the application of any biodegradation factors.

3.2.2 Exceedence of Tier 1 investigation and screening levels

The magnitude of the exceedence should be considered in the context of the CSM (that is, whether the exposure pathways are plausible and whether exposure will result in harm). In cases of minor exceedence of investigation or screening levels, a qualitative risk assessment may be sufficient to evaluate the potential impact.

Where exceedence of Tier 1 investigation and screening levels indicates that there is a likelihood of an adverse impact on human health or ecological values for that site, site-specific health and/or ecological risk assessment (Tier 2 or 3) should be carried out as appropriate. This will usually require the collection of additional site data.

Alternatively, appropriate management options may be considered such as engaging with landowners and occupants/site users regarding the nature of the contamination and implementing appropriate site management plans. Guidance on community engagement and risk communication is provided in Schedule B8.

The nature of the response should be determined on a site-specific basis and be proportional to the potential risk posed to human health and/or the environment.

3.2.3 Procedure if no generic investigation or screening levels are available

Site-specific investigation levels will need to be developed when:

- investigation or screening values are not available for the contaminants of concern and/or insufficient data is available for the derivation of generic guideline values
- site conditions, receptors and/or exposure pathways differ significantly from those assumed in the derivation of the generic investigation or screening levels.

Consult Schedules B4 and B7 for guidance on deriving site-specific HILs and on applying the HIL methodology to derive HILs for additional substances.

Consult Schedule B5b for guidance on applying the EIL methodology to derive EILs for additional substances. Schedule B5b Appendix B provides guidance using a method of soil–water partitioning coefficients for deriving EILs that are protective of aquatic ecosystems.

3.3 Specific considerations for petroleum hydrocarbons

The flowchart in Figure 1 (below) provides a general overview of the application of the HSLs and ESLs for petroleum hydrocarbons including linkage to the ‘management limits’ for TPH contamination. Information on these screening levels can be found in:

Human health concerns

- HSLs check list – ASC NEPM Toolbox
- Vapour inhalation pathway – HSLs – Section 2.4
- Direct contact pathways – HSLs – Section 2.4
- Consumption of groundwater – GILs – Section 2.8 and Schedule B6
- HILs – Benzo(a)pyrene, total PAH and lead – Section 2.2 and Schedule B7
- Aesthetics – Section 3.6
- ‘Management limits’ – Section 2.9.

Ecological concerns

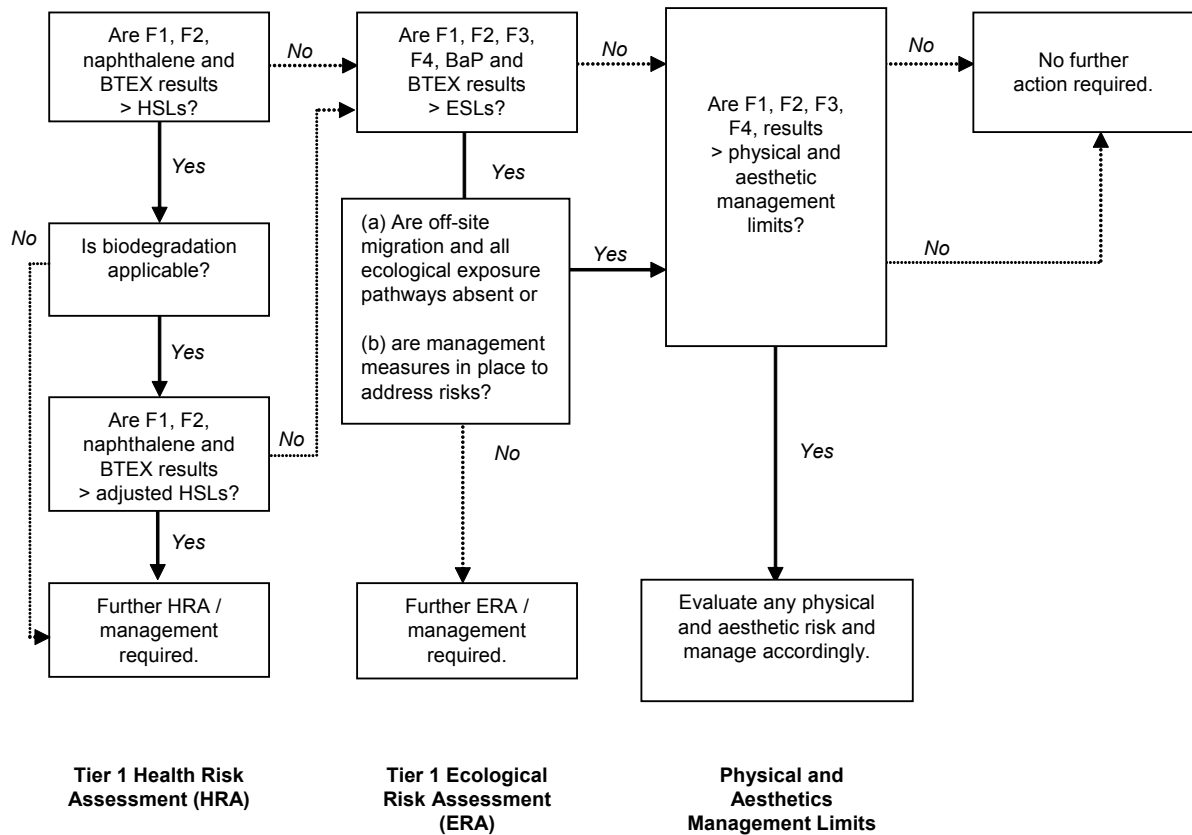
- ESLs – terrestrial ecosystems – Section 2.6
- AQWG – aquatic ecosystems – Section 2.8 and Schedule B6
- EILs – terrestrial ecosystems – lead – Section 2.5.

The application of these screening levels is illustrated by the case studies included in Section 5.

In many cases, sites assessed for petroleum hydrocarbon contamination are driven initially by human health concerns regarding volatile components (F1 and F2). In circumstances where the HSLs are modified by biodegradation factors or where the more volatile fractions are absent, then ecological considerations may become the predominant concern, particularly for the longer chain fractions (F3 and F4).

There are many HSLs that are denoted as non limiting or NL (refer Section 2.4.2, footnotes to HSL Tables and Friebel & Nadebaum (2011a)) and high levels of petroleum hydrocarbons, including observable LNAPL, may be present at the site without presenting a risk via the vapour inhalation pathway. The presence of observable and mobile LNAPL in test pits and bores will require careful consideration of health, environmental, fire and explosive risks and aesthetic concerns. This presentation of LNAPL may lead to active management depending on the current or proposed site use and the extent of the LNAPL. An immediate response may be required where there is penetration of in-ground services or detectable odours in building interiors. Dispersed droplets of LNAPL that are relatively immobile (e.g. in a clay-rich soil) that are assessed as low risk may not require active management.

Figure 1: Flowchart for Tier 1 human and ecological risk assessment of petroleum hydrocarbon contamination – Application of HSLs and ESLs and consideration of management limits



Notes

1. The CSM should inform the selection and application of human health and ecological screening levels and management limits. Relevant HSLs, GILs, HILs and EILs (e.g. PAHs and lead) should be considered for sites affected by petroleum hydrocarbons.
2. The limitations of the screening levels and investigation levels should be considered on a site-specific basis.
3. Petroleum hydrocarbon ‘management limits’ are used to consider the potential effects of LNAPL-related hazards. Refer to Section 2.9 for more information on depth of application. Jurisdictions may have policies applicable to the presence of LNAPL.
4. The potential for groundwater contamination and impacts on receptors including groundwater resources should be considered and assessed as appropriate in accordance with Schedule B6 and jurisdictional policies for the protection of groundwater resources.

3.4 Considerations for ecological assessment

3.4.1 General

Schedule A provides an overview of the site assessment process and the application of investigation and screening levels for human health and ecological risk assessment. While protection of human health often drives the first stages of assessment, protection of the environment (terrestrial and aquatic) should be a consideration for all site assessments.

In assessing the overall risk to the environment from soil contamination the following site-specific aspects should be considered:

- the location of the contamination in relation to any on-site and off-site sensitive receptors, e.g. watercourses, estuaries, groundwater resources, sensitive ecological areas
- the existing or proposed land use(s)
- the presentation of contaminants including areal extent, depth below finished ground level, the presence of barriers or containment that prevents or minimises the migration of contamination or exposure pathways
- the in situ leaching characteristics of contaminants of concern and the potential for leachate to adversely affect any accessible sensitive on-site and off-site receptors
- the potential for contaminants to be transported from the site at levels of concern by erosive forces.

3.4.2 Scope of ecological assessment

The relevance and scope of ecological assessment should be considered early in the development of the conceptual site model and data quality objectives. A pragmatic risk-based approach should be taken in applying EILs and ESLs in residential and commercial/industrial land use settings.

Site soils may have poor structure and drainage, low organic content, minimal topsoil depth and a limited ability to support plant growth and soil micro-organisms. In existing residential and urban development sites there are often practical considerations that enable soil properties to be improved by addition of ameliorants with a persistent modifying effect or by the common practice of backfilling or top dressing with clean soil. In other cases, all of the site soils will be removed during site development works or relocated for the formation of new land forms. Sites may also be backfilled with clean soil/fill and the fate of any excavated contaminated soil should be considered in the process.

Commercial and industrial sites may have large building structures and extensive areas covered with concrete, other pavement or hardstand materials and may have limited environmental values requiring consideration while in operational use.

3.4.3 Mobility of contaminants

When contamination is in a highly leachable form or is incorporated in exposed readily erodible soil, potentially adverse ecological effects may occur some distance from the contaminant source area. The potential for off-site environmental impacts should be considered in the development of the conceptual site model. Methods for determining leachability are discussed in Schedule B3.

It is common for established industrial areas to contain higher levels of soil contamination (such as metals) than surrounding areas. Receptors and soils immediately adjoining older industrial zones may be affected by the accumulation of soil contaminants caused by migration through subsurface contaminant movement and erosion of contaminated soils.

For example, a site with lead (Pb), zinc (Zn) and petroleum hydrocarbon concentrations in soil below EILs and ESLs for commercial/industrial land use (where a 60% or 65% species protection level would apply) would be acceptable for the site use. However, if the site adjoined an area of ecological significance, such as a protected wetland, the site assessment should also consider the possibility that contamination may migrate off-site and impact the wetland where 99% species protection limits would apply.

In other cases sites may have aged metals and metalloid contaminants with stable, cohesive soils and low in situ leachability and pose a low risk to the ecosystem.

3.5 Considerations for groundwater assessment

When groundwater from a monitoring well contains levels of contaminants above the appropriate investigation levels (Tier 1 assessment), then further investigation (Tier 2 assessment) is required. This may take the form of consideration of site-specific conditions and circumstances which may result in modification of the generic Tier 1 criteria. If no modification of the Tier 1 criteria is applicable, the assessment proceeds directly to Tier 3 where groundwater concentrations at the point of exposure (point of use) are compared with the generic GILs or site-specific response levels. If this indicates that the investigation levels are exceeded at the point of use, or in the discharge environment of the groundwater, then an appropriate response is required. The relevant guideline documents should be consulted for informed interpretation and application of GILs and modified GILs.

Groundwater protection may be a particular concern where contamination occurs in sandy soils containing naturally low levels of organic matter, clay and trace elements. In most situations, soil contaminants at levels below appropriate EILs or HILs do not pose a threat to local groundwater sources. However, possible impacts on groundwater should always be considered particularly for sites impacted by petroleum hydrocarbons and halogenated solvents. In some cases the soil may not reveal contaminants of concern while groundwater is affected.

It should be noted that some jurisdictions may have groundwater protection policies that require action even where levels do not exceed the AWQG values at the point of use.

3.6 Aesthetic considerations

3.6.1 Introduction

Aesthetic issues generally relate to the presence of low-concern or non-hazardous inert foreign material (refuse) in soil or fill resulting from human activity. Sites that have been assessed as being acceptable from a human health and environmental perspective may still contain such foreign material. Geotechnical issues related to the presence of fill should be treated separately to assessment of site contamination.

Various forms of refuse may be identified in bore or test pit logs, for example fragments of concrete, metal, bricks, pottery, glass, trivial amounts of bonded asbestos-containing-materials, bitumen, ash, green waste, rubber, plastics and a wide variety of other waste materials. These materials commonly occur in former industrial and filled sites. Similarly, construction and demolition waste materials, some of which are inert and non-hazardous, are widely distributed in urban areas.

Other sites may have some soil discolouration from relatively inert chemical waste (for example, ferric metals) or residual odour (for example, natural sulphur odour).

Care should be taken to ensure adequate site characterisation, particularly when there is a diverse range of foreign material and associated fill and an appreciable risk inferred from site history (or lack thereof) for the presence of hazardous contaminants. For example, some ash fill may contain PAHs and metals, while other ash deposits may contain no contaminants of concern.

3.6.2 Circumstances which would trigger an assessment of aesthetics

The following characteristics or presentations are examples of where site assessment may not have detected contamination above investigation or screening levels but where further assessment would be required:

- highly malodorous soils or extracted groundwater (e.g. strong residual petroleum hydrocarbon odours, hydrogen sulphide in soil or extracted groundwater, organosulfur compounds)
- hydrocarbon sheen on surface water

- discoloured chemical deposits or soil staining with chemical waste other than of a very minor nature
- large monolithic deposits of otherwise low-risk material, e.g. gypsum as powder or plasterboard, cement kiln dust
- presence of putrescible refuse including material that may generate hazardous levels of methane such as a deep-fill profile of green waste or large quantities of timber waste
- soils containing residue from animal burial (e.g. former abattoir sites).

3.6.3 Assessment process for aesthetic issues

There are no specific numeric aesthetic guidelines, however site assessment requires balanced consideration of the quantity, type and distribution of foreign material or odours in relation to the specific land use and its sensitivity. For example, higher expectations for soil quality would apply to residential properties with gardens compared with industrial settings.

General assessment considerations include:

- that chemically discoloured soils or large quantities of various types of inert refuse, particularly if unsightly, may cause ongoing concern to site users
- the depth of the materials, including chemical residues, in relation to the final surface of the site
- the need for, and practicality of, any long-term management of foreign material.

In some cases, documentation of the nature and distribution of the foreign material may be sufficient to address concerns relating to potential land use restrictions.

In arriving at a balanced assessment, the presence of small quantities of non-hazardous inert material and low odour residue (for example, weak petroleum hydrocarbon odours) that will decrease over time should not be a cause of concern or limit the use of a site in most circumstances. Similarly, sites with large quantities of well-covered known inert materials that present no health hazard such as brick fragments and cement wastes (for example, broken cement blocks) are usually of low concern for both non-sensitive and sensitive land uses.

Caution should be used for assessing sensitive land uses, such as residential, when large quantities of various fill types and demolition rubble are present.

4 Asbestos materials in soil

4.1 Scope of the guidance

This guidance applies to the assessment of known and suspected asbestos contamination in soil and addresses both friable and non-friable forms of asbestos. Most assessments will involve non-friable bonded forms of asbestos-containing-material (bonded ACM) as this is the most common type of asbestos soil contamination in Australia.

This guidance is not applicable to asbestos materials which are:

- wastes such as demolition materials present on the surface of the land or
- asbestos materials in buildings or structures including operational pipelines.

Transport and disposal of asbestos-contaminated soil should be carried out in accordance with state and territory legislation and guidelines. Soils that are known or suspected to be contaminated with asbestos should not be reused or recycled at other sites.

This guidance deals with assessment but is closely linked to remediation, management and protection of human health.

An overview of the assessment of asbestos contamination is presented here. More detailed information on site characterisation can be found in Schedule B2 Section 11 and WA DoH (2009, 2012).

Case studies illustrating the recommended approach for site assessment are included in Section 5.

4.2 Historical use of asbestos in Australia

Bonded asbestos products were first manufactured in Australia in the 1920s and were a common component of residential and commercial building materials from the mid-1940s until the late 1980s. Up to 90% of the asbestos mined or imported into Australia was used for the manufacture of these building products. Australia banned the use and import of building asbestos products in the mid-1980s and, in December 2003, banned import, manufacture and use of all asbestos products (e.g. automobile products).

Asbestos has been used in Australia as a reinforcing agent in cement sheeting for walls and roofs and in cement building products, such as pipes, gutters and flooring. Asbestos was also used in combination with other bonding compounds such as vinyl (e.g. for vinyl floor tiles and sheeting) and resin. Friable (non-bonded) asbestos products include low-density asbestos fibre board, insulating products such as lagging, sprays and asbestos rope gaskets.

Many older homes in all Australian communities still contain asbestos cement products, commonly in eaves or cladding of internal and external walls and roofs. When in good condition, bonded asbestos products do not release asbestos fibres into the air and are considered safe for people who are in contact with them, including when carrying and handling these materials (enHealth 2012). If asbestos materials can be maintained in good condition, enHealth (2005, 2012) recommends that these materials are best left alone and periodically checked to monitor their condition.

4.3 Work Health and Safety

Site assessors should be aware of (and where relevant comply with) the requirements of both national and jurisdictional work health and safety legislation and guidance relating to asbestos and its removal, such as:

- the national model Work Health and Safety Regulations and related jurisdictional legislation and guidelines

- *How to manage and control asbestos in the workplace Code of Practice* (Safe Work Australia 2011a)
- *How to safely remove asbestos Code of Practice* (Safe Work Australia 2011b)
- *Code of Practice for the Management and Control of Asbestos in Workplaces* (NOHSC: 2018 (2005))
- *Code of Practice for the Safe Removal of Asbestos 2nd edn* (NOHSC: 2002 (2005)).

State/territory agencies with responsibility for work health and safety should be consulted for specific guidance on what is required in that state or territory.

The final prohibition of asbestos in the workplace came into effect on 31 December 2003 but there are a number of exceptions including:

- genuine research and analysis
- sampling and identification in accordance with WHS Regulations
- where the regulator approves the method adopted for managing risk associated with asbestos.

Safe Work Australia (2011a) provides practical advice on how to manage risks associated with asbestos and asbestos-containing-material (ACM) in the workplace. It provides information on how to identify the presence of asbestos at the workplace and how to implement measures to eliminate or minimise the risk of exposure to airborne asbestos fibres.

Work involving asbestos-contaminated soil is permitted providing that a competent person has determined that the soil does not contain any visible ACM or friable asbestos; or if friable asbestos is visible, it does not contain more than trace levels of asbestos determined in accordance with AS4964:2004 *Method for the qualitative identification of asbestos in bulk samples*.

A competent person is defined in Safe Work Australia (2011a) as a person who has acquired through training, qualification or experience, the knowledge and skills to carry out the task.

A competent person in the context of asbestos and the NEPM is a person who has acquired through training, qualification or experience, the knowledge and skills to identify, investigate and assess asbestos in the context of an environmental site assessment. This includes identifying the potential for asbestos contamination from site history information.

If visible asbestos is present and it may be disturbed during work activities, it must be removed. This includes removing visible fragments of bonded ACM from exposed trench faces and those areas of the site where intrusive works may be carried out (e.g. to install utilities). The removal of visible asbestos should be appropriately managed and full details recorded (this information is required for assessing asbestos concentration in soil – refer Section 4.10). Visible asbestos should be removed prior to excavation/construction works commencing. Consult the relevant Code of Practice for more detailed information.

4.4 Terminology for asbestos contamination in soil

For the purpose of assessing the significance of asbestos in soil contamination, three terms are used in this Schedule which are based on guidance developed by the Western Australian Department of Health (WA DoH, 2009). The equivalent terms used in work health and safety legislation are listed in Table 6:

Table 6 Equivalency of terms used in the NEPM, WA DoH (2009) and Work Health and Safety legislation and guidelines

NEPM terminology (based on WA DoH 2009)	Work Health and Safety terminology
Bonded asbestos-containing-material or 'bonded ACM' (referred to as ACM in WA DoH 2009)	Bonded asbestos/non-friable asbestos
Fibrous asbestos, FA	Non-bonded/friable asbestos
Asbestos fines, AF	

Bonded asbestos containing material (bonded ACM)

Bonded ACM comprises asbestos-containing-material which is in sound condition, although possibly broken or fragmented, and where the asbestos is bound in a matrix such as cement or resin (e.g. asbestos fencing and vinyl tiles). This term is restricted to material that cannot pass a 7 mm x 7 mm sieve. This sieve size is selected because it approximates the thickness of common asbestos cement sheeting and for fragments to be smaller than this would imply a high degree of damage and hence potential for fibre release.

Bonded ACM is equivalent to 'non-friable' asbestos in Safe Work Australia (2011), which is defined therein as 'material containing asbestos that is not friable asbestos, including material containing asbestos fibres reinforced with a bonding compound'.

Fibrous asbestos (FA)

FA comprises friable asbestos material and includes severely weathered cement sheet, insulation products and woven asbestos material. This type of friable asbestos is defined here as asbestos material that is in a degraded condition such that it can be broken or crumbled by hand pressure. This material is typically unbonded or was previously bonded and is now significantly degraded (crumbling).

Asbestos fines (AF)

AF includes free fibres, small fibre bundles and also small fragments of bonded ACM that pass through a 7 mm x 7 mm sieve. (Note that for bonded ACM fragments to pass through a 7 mm x 7 mm sieve implies a substantial degree of damage which increases the potential for fibre release.)

From a risk to human health perspective, FA and AF are considered to be equivalent to 'friable' asbestos in Safe Work Australia (2011), which is defined therein as 'material that is in a powder form or that can be crumbled, pulverised or reduced to a powder by hand pressure when dry, and contains asbestos'.

4.5 Occurrence of asbestos contamination in soil

Bonded ACM is the most common form of asbestos site contamination across Australia, arising from:

- inadequate removal and disposal practices during demolition of buildings containing asbestos products
- widespread dumping of asbestos products and asbestos-containing fill on vacant land and development sites
- commonly occurring in historical fill containing unsorted demolition materials.

If identified early, i.e. prior to significant soil disturbance or earth movements, dumping and inadequate demolition practices usually only results in surface (or near surface) distribution of bonded ACM fragments.

Mining, manufacture or distribution of asbestos products may result in sites being contaminated by friable asbestos including free fibres. Severe weathering or damage (including by vehicle movements)

to bonded ACM may also result in the formation of friable asbestos (comprising fibrous asbestos (FA) and asbestos fines (AF)).

4.6 Asbestos soil contamination and health risk

Asbestos only poses a risk to human health when asbestos fibres are made airborne and inhaled. If asbestos is bound in a matrix such as cement or resin, it is not readily made airborne except through substantial physical damage.

This guidance emphasises that the assessment and management of asbestos contamination should take into account the condition of the asbestos materials and the potential for damage and resulting release of asbestos fibres.

Bonded ACM in sound condition represents a low human health risk. However, both FA and AF materials have the potential to generate, or be associated with, free asbestos fibres. As a result, FA and AF must be carefully managed to prevent the release of asbestos fibres into the air.

It is an inappropriate response to declare a site a human health risk on the basis of the presence of bonded ACM alone. However, if the bonded material is damaged or crumbling (that is, it has become friable), it may represent a significant human health risk if disturbed and fibres are made airborne.

The site-specific assessment of sites contaminated with asbestos in soil should be aimed at describing the nature and quantity of asbestos present in sufficient detail to enable a risk management plan to be developed for the current or proposed land use. The management plan should address potential scenarios for the relevant land use(s) whereby asbestos fibres may become airborne and pose a human health risk.

4.7 Basis for health screening levels for asbestos in soil

In 2009, the Western Australian Department of Health (WA DoH) released *Guidelines for the Assessment, Remediation and Management of Asbestos-Contaminated Sites in Western Australia* (WA DoH 2009). The WA DoH guidelines are based on research published by Swartjes & Tromp (2008), which is based on an extensive database of field and simulation trials using both bound and friable asbestos. The trial results indicated that a soil level of 0.01% for friable asbestos should keep asbestos fibre levels in air below 0.001 fibres per millilitre (f/ml) and probably to around 0.0001 f/ml. This corresponds to a lifetime risk of 10^{-6} to 10^{-5} in the exposed population from airborne asbestos fibres using WHO (2005) risk figures for mesothelioma (WA DoH 2009). The Netherlands (Swartjes & Tromp 2008) apply an investigation level of 0.01% weight for weight (w/w) for fibrous asbestos and 0.1% w/w asbestos for non-friable asbestos (i.e. bound asbestos in sound condition) in soil.

WA DoH has taken a more conservative approach (by a factor of 10) than the Netherlands to take account of the greater dryness and dust-generating potential of many local soils and the practice of treating all forms of asbestos (e.g. crocidolite, amosite, chrysotile and actinolite) as equivalent in terms of human health risk. The WA guidelines apply screening levels of:

- 0.01% w/w asbestos in soil for ACM (being asbestos in bonded ACM) to residential sites equivalent to land use setting HIL A. Additional criteria are provided for other land uses based on the default exposure ratios of the NEPM (1999)
- 0.001% w/w asbestos in soil for FA and AF for all site uses.

4.8 Health screening levels for asbestos in soil

Health screening levels for asbestos in soil, which are based on scenario-specific likely exposure levels, are adopted from the WA DoH guidelines and are listed in Table 7.

There are various acceptable means to provide confidence that the soil surface is free of visible asbestos including, but not limited to, multi-directional raking of soil to about 10 cm depth and hand-

picking of asbestos fragments or covering with a durable hard cover. The requirement for the soil surface to be free of visible asbestos applies to both assessment and remediation phases. Refer to sections 4.10 and 4.11 for guidance on determining asbestos concentration in soil and comparison with these screening levels.

Table 7. Health screening levels for asbestos contamination in soil

Form of asbestos	Health Screening Level (w/w)			
	Residential A ¹	Residential B ²	Recreational C ³	Commercial/Industrial D ⁴
Bonded ACM	0.01%	0.04%	0.02%	0.05%
FA and AF ⁵ (friable asbestos)	0.001%			
All forms of asbestos	No visible asbestos for surface soil			

1. Residential A with garden/accessible soil also includes children's day care centres, preschools and primary schools.
2. Residential B with minimal opportunities for soil access; includes dwellings with fully and permanently paved yard space such as high-rise buildings and apartments.
3. Recreational C includes public open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools and unpaved footpaths.
4. Commercial/industrial D includes premises such as shops, offices, factories and industrial sites.
5. The screening level of 0.001% w/w asbestos in soil for FA and AF (i.e. non-bonded/friable asbestos) only applies where the FA and AF are able to be quantified by gravimetric procedures (refer Section 4.10). This screening level is not applicable to free fibres.

4.9 Process for assessment of asbestos contamination

The recommended general process for assessment of site contamination, including for assessment of asbestos, is shown in Schedule A to this NEPM. The process starts with a Preliminary Site Investigation (PSI), which may lead to a Detailed Site Investigation (DSI). Depending on the site-specific circumstances and the proposed remediation approach, conservative management of presumed asbestos contamination may avoid the need for a DSI. Where remediation is required, appropriate validation sampling should be carried out to verify the effectiveness of the measures undertaken.

It is important to note that inadequate sampling strategies and/or inadequate documentation, rather than lack of accuracy in the adopted analytical methods, characteristically limit the effective evaluation of sites contaminated with asbestos.

Further information on the recommended assessment process is provided in Schedule B2.

A DSI is not necessary where there is a high degree of confidence that the asbestos contamination is confined to bonded ACM in superficial soil, i.e. the site history can be established with confidence and this clearly indicates that there is no reason to suspect buried asbestos materials and the site inspection confirms that any bonded ACM is in sound condition and only present on the surface/near surface of the site. In these circumstances the assessment can proceed directly to remediation (removal of bonded ACM fragments and ensuring that the soil surface is free of visible asbestos) and validation.

4.10 Determining asbestos in soil concentrations

Bonded ACM is the most common and the most readily quantifiable form of asbestos soil contamination due to its ease of visual detection. Where site circumstances are favourable, bonded

ACM in sound condition can be used as the primary means of estimating contamination by subjecting soil samples to on-site sieving and gravimetric procedures as described below.

Assessment of bonded ACM is the recommended measure for total asbestos contamination where FA and AF (derived from bonded ACM only) are not likely to be significant as established by the PSI including the site inspection (as a guide, this may be taken to be where FA and AF are likely to make up less than 10% of the total amount of asbestos present).

Important considerations in determining asbestos concentrations in soil include:

- observations and calculations of surface asbestos occurrence/distribution should be recorded on a grid system (a grid of up to 10 m x 10 m is generally reasonable when large surface areas are impacted, however, non-impacted soils should be excluded from calculations to avoid dilution effects)
- where more than one distinct fill unit or soil stratum/unit is impacted by asbestos materials, separate asbestos determinations should be made for each stratum/unit
- averaging asbestos concentrations across all soils at a site is not appropriate
- for sub-surface samples, (e.g. boreholes and trenches) the calculation should be carried out per sample (i.e. not averaged over a grid square)
- the statistical procedures outlined in Section 3.2 (such as comparing mean concentrations with the screening level and no individual sample concentration exceeding 250% of the screening level) are not appropriate for asbestos
- a weight-of-evidence approach (refer 4.11), which takes into account field observations and methodology and relevant site history findings (e.g. location and nature of fill and demolished buildings etc.)' is recommended for determining whether individual or adjacent samples exceeding the relevant screening levels are of concern.

Asbestos in soil concentration by gravimetric approach

Guidance on recommended sampling methods is given in Schedule B2 and is based on the WA DoH guidelines (2009).

The asbestos concentration calculations are based on the amount of asbestos equivalent (i.e. asbestos in asbestos-containing-materials) in a measured/estimated amount of soil, expressed as a % weight for weight. The soil volume may be one or more individual 10 L samples from specific soil units or the area of a grid square multiplied by the investigation depth for raking and tilling methods (refer Schedule B2).

As outlined in enHealth (2005), the quantity of asbestos in soil may be estimated as follows:

$$\%w/w \text{ asbestos in soil} = \frac{\% \text{ asbestos content} \times \text{bonded ACM (kg)}}{\text{soil volume (L)} \times \text{soil density (kg/L)}}$$

In the example included in enHealth (2005) it was assumed that:

$$\% \text{ asbestos content (within bonded ACM)} = 15\% \text{ and soil density (for sandy soils)} = 1.65 \text{ kg/L}$$

More representative results for asbestos concentration in soil can be calculated if the parameter values are analysed rather than assumed.

The assumption of 15% asbestos by weight in bonded ACM for sites contaminated with cement bonded ACM only is acceptable because typical compositions for bonded ACM products used in Australia are 10–15% asbestos by weight. However, other bonded products may contain much larger proportions of asbestos, e.g. asbestos vinyl floor tiles may contain 8–30% asbestos (Workplace Health and Safety Queensland, 2011). The likely presence of bonded materials other than cement products should be addressed in the PSI and site inspection. If found during sampling, the calculation will need to be adjusted either by making a conservative assumption or based on laboratory analysis of representative material from the site.

Soil densities are typically greater than about 1.5 kg/L (1500 kg/m³). The need to sample and analyse representative soil samples for soil density should be considered in the SAQP and will be required for dense and/or compacted soils.

The rationale for the calculation carried out, including the basis for all assumptions, should be documented in the site assessment report.

Depending on what is known of the site history and also the nature of the investigative methods used, the confidence in the calculation results will vary. In particular, hand-picking (using multi-directional raking and hand removal of fragments) and tilling surveys (mechanical turning over of surface soils to assist identification and collection of fragments) may provide less confidence compared with large volume mechanical screening (separation of fragments by automated sieving). Likewise, if the bonded ACM weight is estimated rather than measured, such as by estimating bonded ACM sheet area, then confidence in the results will be reduced. (Note that when considering which technique(s) to use that the increased confidence in results from mechanical methods should be considered in the context of the possible increased risk of releasing fibres associated with bulk screening.)

A comparable gravimetric assessment approach may be applied to FA when large discrete pieces (e.g. asbestos gaskets and pieces of asbestos ‘rope’) are present in soil, however care should be taken during their removal to minimise potential fibre release.

If bonded ACM is in poor condition or site conditions are likely to result in degradation (e.g. due to acidic soil conditions) then the bonded ACM should be assumed to be FA for the purposes of comparing with the relevant screening level.

Schedule B2 and WA DoH 2009 (Section 4) provide more detailed guidance for sampling soil and determination of the %w/w asbestos in soil by gravimetric procedure.

Laboratory analysis

As yet there is no validated method, readily available in Australia, of reliably estimating the concentration of free asbestos fibres in soil. Soil contamination by free asbestos fibres should therefore be simply determined according to the presence or absence of fibres, in accordance with *AS4964 – 2004: Method for the Qualitative identification of asbestos in bulk samples* (Standards Australia 2004) by a laboratory accredited by NATA (or its mutual recognition agreement partners) for this method.

AS4964-2004 sets out a tiered approach to detecting the presence of asbestos (amosite, crocidolite and chrysotile forms) in soil samples using polarised light microscopy and dispersion staining techniques. If evidence of asbestos fibres is not found in the greater than 2 mm sieved fraction, a trace analysis is required of the residue (sub-2 mm fraction). Depending on the nature and size of the soil sample, the sub-2 mm residue material may need to be sub-sampled for trace analysis.

The nominal detection limit of the AS4964 method is around 0.01%. The examination of large sample sizes (at least 500 ml is recommended) may improve the likelihood of identifying asbestos material in the greater than 2 mm fraction.

Care should be taken in selecting samples for laboratory analysis to ensure that they comprise representative samples, as far as practicable, of the soil units to be tested or material from suspect areas. This may be difficult to achieve because of the complexity of the soil unit or large size of soil particles.

In the case of co-located bonded ACM, FA and AF, where significant asbestos may be present as fibrous asbestos or asbestos fines (greater than 10% (in total for FA and AF) of that present in the bonded ACM alone), then laboratory analysis may be necessary to assist with impact delineation. It may be possible in the initial AS4964 procedure to obtain an estimate of the weight of asbestos (such as small ACM fragments and fibre bundles) which does not pass through the 2 mm sieve. Depending on site circumstances, this information may be useful as part of a weight-of-evidence approach to assessment of asbestos soil concentrations relative to the appropriate screening levels.

As a general guide, where sites are contaminated with bonded ACM only (i.e. no insulation materials or other non-bonded asbestos products) assessment for the presence/absence of free fibres by laboratory analysis is only warranted where greater than 10% of the total bonded ACM is significantly damaged i.e. present as small pieces less than 7 mm x 7 mm or can be crushed/crumbled with hand pressure (significant FA and/or AF is present).

4.11 Assessment against asbestos screening levels and procedure for exceedences

A tiered approach to risk assessment of asbestos contamination is recommended, including development of an appropriate CSM (refer Section 2.4 in Schedule B4).

A weight-of-evidence approach is recommended with consideration given to factors such as the distribution of different fill types, the heterogeneity of the contamination and the uncertainty associated with the sampling methodology. The evaluation and discussion of results should consider any trends across the investigated area including variability and change in asbestos type and condition. For buried asbestos contamination, the impacted units should be identified and discussed separately.

For Tier 1 analysis, the contamination concentrations are compared with the screening levels presented in Section 4.8. If the Tier 1 screening levels are not exceeded, and an appropriate level of investigation has been carried out, then no contamination management actions are required except for ensuring the surface soil is free of visual asbestos. This may be achieved by multidirectional raking or tilling and hand-picking of exposed fragments of bonded ACM. Final visual inspection of the assessment and remediated areas should not detect any visible asbestos.

When cohesive soils (such as firm clay) or a large surface area is involved it may be more practical to skim the top 5–10 cm of soil for disposal in accordance with jurisdictional requirements. The exposed surface of the site can then be further visually assessed by an appropriately qualified and experienced professional/competent person on a systematic basis. If bonded ACM fragments are found to be present after skimming, some localised hand-picking or additional earthworks may be required until no visible bonded ACM is present.

If exceedences of the Tier 1 screening levels are present, either a Tier 2 analysis should be carried out or a conservative management response implemented. The Tier 2 assessment will comprise a qualitative assessment of risk in many cases and should take into account the nature and extent of contamination; the site-specific exposure scenario(s) including the intensity of relevant site activities; the impact of any mitigating factors such as soil type and soil moisture conditions (and likely variation); the proposed remediation and management measures; and the final use of the site.

Remediation options which minimise soil disturbance and therefore public risk are preferred. Management of asbestos in situ is encouraged, which may include covering the contamination with uncontaminated fill or other protective or warning layers. It should be noted that the common alternative of complete removal of asbestos from a site often involves extensive and costly

investigative and validation sampling and may not be effective or necessary for the protection of human health.

Regulatory authorities may consider statutory management controls to land with substantial asbestos contamination to ensure that appropriate management conditions, including land use limitations, apply to the site. These controls may include notation on title, approved management and listing on public site contamination registers or ongoing controls under audit statements and planning controls, as relevant for the jurisdiction.

Additional information on the assessment approach is provided in Schedule B2 and WA DoH (2009 and 2011).

Further information on risk assessment, remediation and management procedures can be found in Section 5 of the WA DoH Guidelines (2009).

The recommended approach for circumstances involving bonded ACM (the commonest form of asbestos contamination) is illustrated by the included case studies.

5 Case Studies

Case study 1	Assessment of asbestos contamination in soil - poor demolition practice at a residential site
Case study 2	Assessment of asbestos contamination in soil - redevelopment of an industrial site for residential use
Case study 3	Application of petroleum hydrocarbon screening levels - redevelopment of an industrial site for residential use
Case study 4	Application of soil vapour interim VOCC HILs and HSLs - vapour intrusion assessment for a commercial building adjacent to industrial premises
Case study 5	Application of HILs and EILs - redevelopment of an industrial site for residential use

For the purposes of illustration, selected summary data only is presented and it can be assumed that the raw data has been evaluated in accordance with the guidance in Section 11 Schedule B2 and that the data has been assessed as being accurate and representative of the site.

<p>Case study 1 - Assessment of asbestos contamination in soil - poor demolition practices at a residential site</p>
<p>Site scenario</p> <p>Typical low density residential site (individual house site) where poor demolition practices have resulted in fragments of bonded ACM being scattered over discrete area(s) of the site surface. In this scenario, there are no substantial fill materials or other sources of potential contamination present at the site. The demolition has occurred in the recent past and no further soil disturbing activities, including removal of sub-surface utilities, have taken place since the buildings were demolished.</p> <p>Response</p> <p>Conduct a PSI and a grid-based site inspection survey (walkover) including detailed notes of bonded ACM distribution and condition and nature of surface soils.</p> <p>A DSI is not necessary provided that the contamination is only at surface/near surface and the bonded ACM is in good condition (non-friable).</p> <p>The extent of the affected area(s) should be carefully documented and all visible asbestos removed. As the site walkover confirmed that the surface soils were sandy, fragments of bonded ACM can be removed effectively by raking and hand-picking (refer WA DoH (2009) for details of recommended methodology). Sufficient raking passes should be conducted to ensure that the raked depth (approximately 10 cm) is free of visible asbestos.</p>

In this scenario, it is not necessary to sample and analyse surface soils to confirm that no asbestos fibres are present given that the only type of asbestos present is bonded ACM and that it is not severely weathered.

Case study 2 - Assessment of asbestos contamination in soil - redevelopment of an industrial site for residential use

Site Scenario

A former industrial site is proposed for redevelopment for high density residential land use. The site was historically filled in some areas with material containing bonded ACM to approximately 3 m depth (possibly as a result of poor demolition practices). More recently, the contaminated fill was covered by approximately 0.5 m of clean soil as an interim management measure. The proposed development will require that there is major site excavation to >3 m as well as alteration of the land form. Although broken, the bonded ACM fragments appear in reasonable condition and are not easily crumbled i.e. not fibrous asbestos. There is no evidence from the site history or direct observation during the initial site walkover that other fibrous asbestos materials (such as insulation or woven materials) are present on the site. Other non-asbestos soil contaminants may be present.

Response

In this redevelopment scenario, there are two potential options:

- Option A - excavate all the affected fill (and validate the work undertaken including that no visible asbestos is present on the site surface) and either manage by containment on-site or off-site disposal at an appropriate waste facility
- Option B - carry out a DSI to delineate the volume of contaminated soil requiring on-site containment or off-site disposal

The size of the site, the potential volume of affected fill and the practicality (including regulatory requirements) of containing asbestos-contaminated soil on-site, are likely to influence the decision taken.

The following steps outline Option B - the DSI approach:

- 1 **Preliminary site investigation** - desktop study and detailed site inspection
 - collect information on the location, condition and amount of bonded ACM present on the site surface to inform the SAQP for the DSI.
- 2 **Preparation of the Sampling and Analysis Quality Plan (SAQP)** - A conceptual site model (CSM) and data quality objectives (DQOs) should be developed which identify all the site-specific contaminants of concern including relevant forms of asbestos and the potential human health risks (refer Schedule B2).
 - the sampling program should account for the potentially non-homogenous distribution and condition of bonded ACM in soil, for example using judgemental sampling involving a detailed test pit and trenching program to identify the lateral and vertical distribution
 - photographic logging of test pits and trenches will assist documentation for site assessment
 - qualitative laboratory analysis may be required to confirm that representative pieces of suspect bonded ACM and other suspect material (if found during the site walkover or during test pitting and trenching) contain asbestos.
 - soil sampling for the detection of asbestos fibres released from fragments of bonded ACM is not required where the bonded ACM is in good/reasonable condition.
 - if fibrous asbestos (such as severely weathered bonded ACM or insulation materials)

is not observed during the field sampling program or indicated by the laboratory analysis of the selected suspect materials, no further consideration or action for this form of asbestos is required

- if asbestos fibres are detected by qualitative laboratory analysis, appropriate remediation and management action will be required (a conservative management approach which does not rely on extensive soil sampling for the presence/absence of asbestos fibres is recommended).

3 *Intrusive investigation to delineate impacted area*

- gravimetric analysis of each fill area will be required and the bonded ACM results for each area compared with the relevant screening level
- a weight-of-evidence approach should be adopted for the assessment with consideration given to the distribution of different fill types, the heterogeneity of the contamination (including condition of bonded ACM) and the uncertainty associated with the sampling methodology
- if there is uncertainty that the screening level is exceeded, additional systematic sampling and gravimetric determination could be undertaken or a conservative approach to management adopted
- areas where the screening levels are not exceeded require no further action or assessment in relation to asbestos other than ensuring that no visible asbestos is present at surface.

4 *Management/remediation* of areas of elevated levels of bonded ACM and/or fibrous asbestos by

- bulk screening of impacted site soils to remove bonded ACM (only feasible for sandy soils)
- on-site containment in accordance with jurisdictional requirements¹ or
- disposal to an appropriate waste facility
- no visible asbestos should be present at the completion of remediation works.

¹ These requirements will consider human health risks arising from current and potential future land uses. They may include mandating of barrier layers, containment cells, depth of burial, ongoing monitoring and other statutory conditions of site use (e.g. as listed in a site management plan).

Case study 3 - Application of petroleum hydrocarbon screening levels - redevelopment of an industrial site for residential use

Site Scenario - Former small-scale regional fuel depot proposed for low-density residential use

After the site ceased to operate as a fuel depot in the mid-1980s, all tanks were removed and the site is understood to have been filled with clean silt to 2 m depth shortly after the depot was decommissioned. For the past 15 years the site has been used for storage of motor vehicles and agricultural equipment.

Response

A PSI was carried out and an initial CSM developed. The site has been investigated (including the 'clean' fill) according to an appropriate SAQP informed by the CSM. A source of contamination has been identified in the unsaturated zone which has an associated contaminated groundwater plume. Depth to groundwater is approximately 6 m. Soil and groundwater samples have been analysed for TRH fractions, BTEX, PAHs and lead.

It can be assumed for the purpose of this case study that the maximum slab width for the proposed residential dwellings is less than 15 m.

Summary of site contamination

- A preliminary screening step (refer Section 9.2.1 of Schedule B2) has determined that an assessment of potential vapour intrusion risks is necessary as receptors (residents of houses) are to be located within 30 m of an identified volatile source.
- The HSL assumptions and limitations were checked with the aid of the HSL checklist (ASC NEPM Toolbox) and the HSLs confirmed to be applicable for the site-specific conditions.
- BTEX and naphthalene were subtracted from TRH fractions $C_6 - C_{10}$ and $>C_{10} - C_{16}$ to obtain F1 and F2 respectively.
- Fill layer 0–2 m below ground level – 95% UCL for all the identified contaminants of concern was less than the appropriate investigation and screening levels.
- Soil Type: The borelogs indicate silt and silty clay, predominant soil type determined to be silt (the HSLs for silt are more conservative than those for clay).
- The geometric mean (GM) for TRH and BTEX in soil for 2–4 m is tabulated below.
- All individual soil results are less than 2.5x the relevant investigation and screening levels; hotspots, if present, would need to be considered separately.
- No contamination of concern was found below 4 m in soil.
- Poor quality groundwater was found at 6 m in three wells MW1, MW2, MW3 (saline, TDS >5000 mg/L, low yield <2 L/sec)
- The maximum concentrations (based on quarterly monitoring results carried out over one year) for TRH and BTEX in groundwater are listed below.
- Soil vapour oxygen measurements of 9–10% were measured at 1 m depth at five locations above the soil source.

Step 1: Document results and select relevant soil and groundwater HSLs

Soil GM values mg/kg, refer Table 1A(3) for soil HSLs (silt, 2–<4 m)

	F1	F2	F3	F4	B	T	E	X
Soil GM	130	160	1100	260	1.5	80	70	60
HSL A	100	NL	N/A	N/A	1.0	NL	NL	NL

Notes

NL indicates the HSL is not limiting (see Footnote 5, Table 1A(3)).

N/A not applicable as these fractions are not volatile and hence are not of concern for vapour intrusion

Shaded and bold font for sample value indicates relevant HSL exceeded

Groundwater (site maximum concentration) values mg/L, refer Table 1A(4) for groundwater HSLs (silt, 4 m to <8 m)

	F1	F2	F3	F4	B	T	E	X
MW1	1.3	0.9	<LOR	<LOR	7	16	12	35
MW2	0.5	<LOR	<LOR	<LOR	<LOR	<LOR	<LOR	4
MW3	2.7	1.1	<LOR	<LOR	8	17	23	42
HSL A	6	NL	N/A	N/A	5	NL	NL	NL

Notes

LOR is the limit of reporting.

NL indicates the HSL is not limiting (see Footnote 4, Table 1A(4)).

N/A not applicable as these fractions are non-volatile and hence are not of concern for vapour intrusion

Shaded and bold font for sample value indicates relevant HSL exceeded

Step 2: Tier 1 risk assessment

1. **Are site values greater than soil and groundwater HSLs for assessing vapour intrusion risks? YES, elevated F1 and benzene in soil and elevated benzene in groundwater.**
2. **Is biodegradation applicable? YES (from consideration of likely slab size for a typical residential house and oxygen content of soil vapour at 1m) Adjust soil HSLs x10 (soil depth 2 – 4 m) and groundwater HSLs x100 (depth to groundwater 6 m) (see Notes Table 1A(3) and Table 1A(4) and Friebe & Nadebaum 2011a).**

Adjusted HSL values for soil and groundwater -biodegradation factors applied

HSL	F1	F2	F3	F4	B	T	E	X
Soil 2-4 m	NL	NL	N/A	N/A	10	NL	NL	NL
Groundwater 4 m to <8 m	NL	NL	N/A	N/A	50	NL	NL	NL

Notes

Confirmation of soil oxygen > 5% at 1 m depth allows a biodegradation factor of x10 for vapour sources from 2 m-<4 m. Similarly, a biodegradation factor of x100 applies to groundwater vapour sources >4 m which takes adjusted HSLs to above the non limiting threshold value except for benzene in the example above.

NL indicates the HSL is not limiting (see Footnote (5) Table 1A(3) and Footnote (4) Table 1A(4) .

N/A not applicable as these fractions are non-volatile and hence not of concern for vapour inhalation

3. **Are site values greater than adjusted HSLs for vapour intrusion? NO**
4. **Are direct contact HSLs relevant? YES (proposed low density residential land use) however there is no soil contamination at surface (95% UCL for all the identified contaminants of concern was less than the appropriate investigation and screening levels).**

5. **Are ecological considerations relevant?** *YES (proposed low density residential development with exposed areas of soil).* Site summary information indicates that the soil GM for 0–2 m was less than the applicable ESLs. A comparison with soil data for deeper horizons is not relevant as the ESLs are applicable to the top 2 m of soil.
6. **Are management limits relevant?** *YES (decommissioned industrial site proposed for sensitive land use).* Compare soil results with the relevant management limits for residential use. NO exceedences indicated.

'Clean fill' and soil values mg/kg, refer Table 1B(7) for management limits (fine soil)

	F1	F2	F3	F4
Fill GM 0 – 2 m	<10	< 10	<50	<100
Soil GM 2 – 4 m	130	160	1,100	260
Management limit	800	1,000	3,500	10,000

7. **Are aesthetics relevant?** *YES (sensitive land use proposed)* As 2 m of clean fill is present across the site issues of soil staining or odours are unlikely. The assessor will also need to consider the likelihood of uncontrolled excavations exposing contaminated material at depth.

Outcome	
	<ul style="list-style-type: none"> No exceedences are indicated from the comparisons with the relevant HSLs, ESLs and management limits for the proposed residential land use. Evaluation of the data for naphthalene, BaP, total PAHs and lead would also be required.

Evaluation and conclusion

A multiple-lines-of-evidence approach is recommended for the evaluation of vapour intrusion risks. Although no unacceptable vapour intrusion risks were identified in the assessment above, the assessor would need to take into account the level of uncertainty associated with the data and whether a sufficient margin of safety was present, particularly in relation to the adjusted groundwater HSLs.

Further consideration should be given to the confidence in the site CSM particularly with regards to seasonal trends in groundwater quality and possible variation in depth to the water table. If the watertable is likely to rise by more than 2 m, then the maximum concentrations of benzene recorded in MW 1 (7 mg/L) and MW3 (8 mg/L) would be close to/at the level of the adjusted HSL of 8 mg/L for 2 m – <4 m depth (Table 1A(4) with x10 adjustment).

Given the sensitivity of the proposed land use (low density residential), consideration should be given to collecting further data such as conducting a soil vapour survey of the source area.

The level of groundwater contamination present is of concern. The groundwater quality is unacceptable for human consumption and should be restricted for use by site occupants. Potable use is unrealistic given the poor groundwater quality and yield, however, it could cause adverse effects on potential ecosystem receptors. Further consideration should be given to groundwater contamination regarding any potential receptors off-site and any realistic future use potential. State and local groundwater protection policies would take effect in applying controls over the presence, extraction and use of impacted groundwater.

Note, it would not be an appropriate approach to install a thickness of fill to cover hydrocarbon contamination to enable the use of less stringent HSLs or to enable the application of a 'x10' or 'x100' biodegradation factor.

Case study 4: Application of soil vapour interim VOCC HILs and HSLs - vapour intrusion assessment for a commercial building adjacent to industrial premises

Site Scenario

A drum reconditioning works is located beside a four-storey office building in an industrial estate. A drum pre-clean area attached to the works has leaked chemical wastes to the subsurface. Limited soil and groundwater sampling, constrained by existing infrastructure and land uses, have detected TCE, PCE and derivatives, BTEX and TRH fractions in soil and groundwater bores. Initial results suggested a potential human health risk to ground floor occupants of the office block. The surface of the site comprises sealed hardstand.

Response

The soil and groundwater sampling has been followed up with soil vapour samples at 0–1 m depth located in the bituminised area immediately adjacent to the office block at four locations to further assess the human health risk.

- A preliminary screening step (refer Section 9.2.1 of Schedule B2) has determined that an assessment of potential vapour intrusion risks is necessary as receptors (occupants of office block) are located within 30 m of an identified volatile source.
- The HSL assumptions and limitations were checked with the aid of the HSL checklist – (ASC NEPM Toolbox) and the HSLs confirmed to be applicable for the site-specific conditions.
- BTEX and naphthalene were subtracted from TRH fractions C₆ – C₁₀ and >C₁₀ – C₁₆ to obtain F1 and F2 respectively (note F2 data not presented here).
- Soil Type - Predominant soil type determined to be sand.
- Biodegradation is not a consideration as the office block concrete slab and contiguous bituminised area is >15 m wide.
-

Step 1: Document results and select interim VOCC HILs and soil vapour HSLs

Soil vapour values mg/m³, refer Table 1A(2) for interim VOCC HILs and Table 1A(5) for soil vapour HSLs for 0-1 m (sand)

Sample	TCE	PCE	Vinyl chloride	B	T	E	X	F1
SG1	22	110	6	7	25	44	60	120
SG2	30	130	17	9	60	52	40	200
SG3	7	75	1.5	5	8	18	20	80
SG4	4	30	1.3	3	10	21	25	70
Interim HIL or HSL	0.02	2	0.03	1	1,300	330	220	180

Note: Shaded and bold font for sample value indicates relevant interim VOCC HIL or HSL is exceeded.

Step 2: Tier 1 risk assessment

1. **Are results greater than the soil vapour HSLs?** YES, benzene exceeds the HSL in all locations and F1 in one location.
2. **Are results greater than the soil vapour interim VOCC HILs?** YES, TCE, PCE and vinyl chloride exceed the interim HILs for VOCCs in all sampling locations.
3. **Are ecological considerations relevant?** NO for on-site only (commercial industrial development with no exposed areas of soil and continuing industrial use).
4. **Are petroleum management limits exceeded?** No (Compare results to management limits in Table 1B(7). F1 results do not exceed the management limits.)

Outcome	<ul style="list-style-type: none">• Results of Tier 1 assessment show exceedences of the HSL for benzene and interim VOCC HILs for TCE, PCE and vinyl chloride. Further assessment (Tier 2) or management action is required for these contaminants.
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Evaluation and conclusion

The results indicate a potentially serious human health risk via the vapour inhalation pathway from benzene, TCE, PCE and VOCC derivatives to ground floor occupants of the office building. As the exceedences are 2–4 orders of magnitude above the interim soil vapour HILs, an immediate response is required to protect human health such as indoor air sampling to determine actual exposure and/or implementing mitigation measures.

This example is limited to consideration of health risks from selected petroleum hydrocarbons and VOCC inhalation exposure. Additional assessment would be required for other petroleum hydrocarbons and also to evaluate any off-site ecological risks for example via infiltration of contaminated groundwater into sewer or stormwater drainage systems and/or discharge into a sensitive receptor.

**Case study 5 - Use of HILs and EILs -
redevelopment of an industrial site for residential use**

Site Scenario

The site is a former electroplating works and is proposed for residential townhouse development with individual gardens. Prior to industrial use, the whole site was filled from 0 to 1 m with imported clay/soil fill of uniform characteristics.

Response

The site was assessed by a detailed sampling program based on a well-documented site history and no contamination of concern was found below 2 m. Based on site history, CrVI was included in the sampling and analysis but not detected. Representative samples of site soils were analysed for cation exchange capacity (CEC), clay content and pH to assist with ecological assessment.

For the purposes of illustration, the generalised geometric mean (GM) data shown below is assumed to be sufficient from a statistical basis to describe and evaluate the condition of the site. All relevant contaminants of concern were identified and the original surface stratum has uniform characteristics across the site. Hot spots, if present, would need to be considered separately.

Step 1: Document soil results and select HILs

Depth (m)	Cu mg/kg	Zn mg/kg	Ni mg/kg	CrIII mg/kg	CEC (cmol/kg)	pH pH units	% Clay %
0-1	540	890	660	1100	9	6.0	10
1-2	170	470	380	400	17	6.5	12
HIL A	6,000	7,400	400	N/A	-	-	-

Note: N/A= not applicable due to the low human toxicity of CrIII.

Shaded and bold font for sample value indicates HIL exceeded.

Step 2: Tier 1 health risk assessment

1. Are site values greater than HILs? YES, elevated Ni level requires further health risk assessment.

Step 3: Tier 1 ecological risk assessment

2. Determine site EILs (EIL = ABC + ACL) or use the EILs spreadsheet in the ASC NEPM Toolbox.
3. Determine the added contaminant limits (ACLs)

Examination of the site history indicates that the contamination has been present for over 2 years and therefore ACLs for aged contamination are appropriate. To determine site ACLs, refer Table 1B(1) for Zn, Table 1B(2) for Cu and Table 1B(3) for CrIII and Ni. Establish the site ACL for the appropriate land use and with consideration of the soil-specific pH, clay content or CEC as required. Select the nearest ACL value in the CEC table. The ACL for Cu may be determined by pH or CEC and the lower of the determined values should be selected for EIL calculation.

Site ACLs (mg/kg)	Depth (m)	Cu	Zn	Ni	CrIII
	0-1	190	400	170	400
	1-2	210	590	270	400

4. Measure the ambient background (ABC) at an appropriate reference location.

- 0–1 m clay/soil fill, sampled from filled area at rear of property known to be unaffected by subsequent industrial activity.
- 1–2 m, sample of uncontaminated strata from adjacent site.

	Depth (m)	Cu	Zn	Ni	CrIII
ABC (mg/kg)	0–1	4	65	2	7
	1–2	1.5	8	0.5	10

5. Calculate the site EILs (ABC + ACL)

	Depth (m)	Cu	Zn	Ni	CrIII
Site EILs (mg/kg)	0–1	194	465	172	407
	1–2	211.5	598	270.5	410

- Round results for reasons of consistency and avoidance of false accuracy¹

	Depth (m)	Cu	Zn	Ni	CrIII
Site EILs (mg/kg)	0–1	190	465	170	410
	1–2	210	600	270	410

6. Compare site data with EILs

	Depth (m)	Cu	Zn	Ni	CrIII
Site data (mg/kg)	0–1	540	890	660	1100
	1–2	170	470	380	400

Note: Shaded and bold font for sample values indicates EIL exceeded

Are results greater than EILs? YES, Cu, Zn, Ni and CrIII exceed EILs – further investigation required.

Tier 1 outcome	Exceedences of the HIL for Ni and EILs for Cu, Zn, Ni and Cr III.
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Evaluation and conclusion

¹ The following rounding rules are applicable to the EILs

- Nos < 1 to nearest 0.1
- 1 - <10 to nearest integer
- 10 - < 100 to nearest 5
- 100 - <1000 to nearest 10
- ≥1000 to nearest 100

The geometric mean exceedences are 2–3 times the relevant screening level hence further investigation or management is required.

This example is limited to consideration of risks from exposure to metals in soil. Additional assessment would be required to evaluate groundwater issues at the site.

6 Tabulated investigation and screening levels

ROUNDING APPLIED TO INVESTIGATION AND SCREENING LEVELS

Tables 1A (HILs and interim HILs)

Rounded to 1 or 2 significant figures (see Schedule B7 Appendix C for details)

Tables 1A (HSLs) and 1B (EILs and ESLs) rounding rules

< 1	to nearest 0.1
1–<10	to nearest whole number
1–< 100	to nearest 5
100–<1,000	to nearest 10
1,000–<10,000	to nearest 100
≥10,000	to nearest 1,000

Numbers ending in '5' are rounded up, for example:

0.05 rounded to 0.1
1.5 rounded to 2
115 rounded to 120

Table 1A(1) Health investigation levels for soil contaminants

Chemical	Health-based investigation levels (mg/kg)			
	Residential ¹ A	Residential ¹ B	Recreational ¹ C	Commercial/ industrial ¹ D
Metals and Inorganics				
Arsenic ²	100	500	300	3 000
Beryllium	60	90	90	500
Boron	4500	40 000	20 000	300 000
Cadmium	20	150	90	900
Chromium (VI)	100	500	300	3600
Cobalt	100	600	300	4000
Copper	6000	30 000	17 000	240 000
Lead ³	300	1200	600	1 500
Manganese	3800	14 000	19 000	60 000
Mercury (inorganic) ⁵	40	120	80	730
Methyl mercury ⁴	10	30	13	180
Nickel	400	1200	1200	6 000
Selenium	200	1400	700	10 000
Zinc	7400	60 000	30 000	400 000
Cyanide (free)	250	300	240	1 500
Polycyclic Aromatic Hydrocarbons (PAHs)				
Carcinogenic PAHs (as BaP TEQ) ⁶	3	4	3	40
Total PAHs ⁷	300	400	300	4000
Phenols				
Phenol	3000	45 000	40 000	240 000
Pentachlorophenol	100	130	120	660
Cresols	400	4 700	4 000	25 000
Organochlorine Pesticides				
DDT+DDE+DDD	240	600	400	3600
Aldrin and dieldrin	6	10	10	45
Chlordane	50	90	70	530
Endosulfan	270	400	340	2000
Endrin	10	20	20	100
Heptachlor	6	10	10	50
HCB	10	15	10	80
Methoxychlor	300	500	400	2500
Mirex	10	20	20	100
Toxaphene	20	30	30	160
Herbicides				
2,4,5-T	600	900	800	5000
2,4-D	900	1600	1300	9000
MCPA	600	900	800	5000

Chemical	Health-based investigation levels (mg/kg)			
	Residential ¹ A	Residential ¹ B	Recreational ¹ C	Commercial/ industrial ¹ D
MCPB	600	900	800	5000
Mecoprop	600	900	800	5000
Picloram	4500	6600	5700	35000
Other Pesticides				
Atrazine	320	470	400	2500
Chlorpyrifos	160	340	250	2000
Bifenthrin	600	840	730	4500
Other Organics				
PCBs ⁸	1	1	1	7
PBDE Flame Retardants (Br1–Br9)	1	2	2	10

Notes:

(1) Generic land uses are described in detail in Schedule B7 Section 3

HIL A – Residential with garden/accessible soil (home grown produce <10% fruit and vegetable intake (no poultry), also includes childcare centres, preschools and primary schools.

HIL B – Residential with minimal opportunities for soil access; includes dwellings with fully and permanently paved yard space such as high-rise buildings and apartments.

HIL C – Public open space such as parks, playgrounds, playing fields (e.g. ovals), secondary schools and footpaths. This does not include undeveloped public open space where the potential for exposure is lower and where a site-specific assessment may be more appropriate.

HIL D – Commercial/industrial, includes premises such as shops, offices, factories and industrial sites.

- (2) Arsenic: HIL assumes 70% oral bioavailability. Site-specific bioavailability may be important and should be considered where appropriate (refer Schedule B7).
- (3) Lead: HIL is based on blood lead models (IEUBK for HILs A, B and C and 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) Methyl mercury: assessment of methyl mercury should only occur where there is evidence of its potential source. It may be associated with inorganic mercury and anaerobic microorganism activity in aquatic environments. In addition the reliability and quality of sampling/analysis should be considered.
- (5) Elemental mercury: HIL does not address elemental mercury. A site-specific assessment should be considered if elemental mercury is present, or suspected to be present,
- (6) Carcinogenic PAHs: HIL is based on the 8 carcinogenic PAHs and their TEFs (potency relative to B(a)P) adopted by CCME 2008 (refer Schedule B7). The B(a)P TEQ is calculated by multiplying the concentration of each carcinogenic PAH in the sample by its B(a)P TEF, given below, and summing these products.

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

Where the B(a)P occurs in bitumen fragments it is relatively immobile and does not represent a significant health risk.

- (7) Total PAHs: HIL is based on the sum of the 16 PAHs most commonly reported for contaminated sites (WHO 1998). The application of the total PAH HIL should consider the presence of carcinogenic PAHs and naphthalene (the most volatile PAH). Carcinogenic PAHs reported in the total PAHs should meet the B(a)P TEQ HIL. Naphthalene reported in the total PAHs should meet the relevant HSL.
- (8) PCBs: HIL relates to non-dioxin-like PCBs only. Where a PCB source is known, or suspected, to be present at a site, a site-specific assessment of exposure to all PCBs (including dioxin-like PCBs) should be undertaken.

Table 1A(2) Interim soil vapour health investigation levels for volatile organic chlorinated compounds

Chemical	Interim soil vapour HIL (mg/m ³)			
	Residential ¹ A	Residential ¹ B	Recreational ¹ C	Commercial / Industrial ¹ D
TCE	0.02	0.02	0.4	0.08
1,1,1-TCA	60	60	1200	230
PCE	2	2	40	8
cis-1,2-dichloroethene	0.08	0.08	2	0.3
Vinyl chloride	0.03	0.03	0.5	0.1

Notes:

1. Land use settings are equivalent to those described in Table 1A(1) Footnote 1 and Schedule B7, though secondary school buildings should be assessed using residential 'A/B' for vapour intrusion purposes.
2. Interim HILs for VOCCs are conservative soil vapour 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 using an indoor air-to-soil vapour attenuation factor of 0.1 and an outdoor air-to-soil vapour attenuation factor of 0.05.
3. Application of the interim HILs is based on a measurement of shallow (to 1 m depth) soil vapour (or deeper where the values are to be applied to a future building with a basement) or sub-slab soil vapour.
4. The applicability of the interim HILs needs to be further considered when used for other building types such as homes with a crawl-space and no slab, which may require site-specific assessment.
5. Use of the interim HILs requires comparison with data that has been collected using appropriate methods and meets appropriate data quality requirements.
6. Oral and dermal exposure should be considered on a site-specific basis where direct contact exposure is likely to occur.

Table 1A(3) Soil HSLs for vapour intrusion (mg/kg)

CHEMICAL	HSL A & HSL B Low - high density residential				HSL C recreational / open space				HSL D Commercial / Industrial				Soil saturation concentration (C _{sat})
	0 m to <1 m	1 m to <2 m	2 m to <4m	4 m+	0 m to <1 m	1 m to <2 m	2 m to <4 m	4 m+	0 m to <1 m	1 m to <2 m	2 m to <4 m	4 m+	
SAND													
Toluene	160	220	310	540	NL	NL	NL	NL	NL	NL	NL	NL	560
Ethylbenzene	55	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	64
Xylenes	40	60	95	170	NL	NL	NL	NL	230	NL	NL	NL	300
Naphthalene	3	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	9
Benzene	0.5	0.5	0.5	0.5	NL	NL	NL	NL	3	3	3	3	360
F1 ⁽⁹⁾	45	70	110	200	NL	NL	NL	NL	260	370	630	NL	950
F2 ⁽¹⁰⁾	110	240	440	NL	NL	NL	NL	NL	NL	NL	NL	NL	560
SILT													
Toluene	390	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	640
Ethylbenzene	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	69
Xylenes	95	210	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	330

	HSL A & HSL B Low - high density residential				HSL C recreational / open space				HSL D Commercial / Industrial				
Naphthalene	4	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	10
Benzene	0.6	0.7	1	2	NL	NL	NL	NL	4	4	6	10	440
F1⁽⁹⁾	40	65	100	190	NL	NL	NL	NL	250	360	590	NL	910
F2⁽¹⁰⁾	230	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	570
CLAY													
Toluene	480	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	630
Ethylbenzene	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	68
Xylenes	110	310	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	330
Naphthalene	5	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	10
Benzene	0.7	1	2	3	NL	NL	NL	NL	4	6	9	20	430
F1⁽⁹⁾	50	90	150	290	NL	NL	NL	NL	310	480	NL	NL	850
F2⁽¹⁰⁾	280	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	NL	560

Notes:

- (1) Land use settings are equivalent to those described in Table 1A(1) Footnote 1 and Schedule B7. HSLs for vapour intrusion for high density residential assume residential occupation of the ground floor. If communal car parks or commercial properties occupy the ground floor, HSL D should be used,
- (2) The key limitations of the HSLs should be referred to prior to application and are presented in Friebel and Nadebaum (2011b and 2011d).
- (3) Detailed assumptions in the derivation of the HSLs and information on how to apply the HSLs are presented in Friebel and Nadebaum (2011a and 2011b).
- (4) Soil HSLs for vapour inhalation incorporate an adjustment factor of 10 applied to the vapour phase partitioning to reflect the differences observed between theoretical estimates of soil vapour partitioning and field measurements. Refer Friebel & Nadebaum (2011a) for further information.
- (5) The soil saturation concentration (C_{sat}) is defined as the soil concentration at which the porewater phase cannot dissolve any more of an individual chemical. The soil vapour that is in equilibrium with the porewater will be at its maximum. If the derived soil HSL exceeds C_{sat}, a soil vapour source concentration for a petroleum mixture could not exceed a level that would result in the maximum allowable vapour risk for the given scenario. For these scenarios, no HSL is presented for these chemicals and the HSL is shown as 'not limiting' or 'NL'.

- (6) The HSLs for TPH C₆-C₁₀ in sandy soil are based on a finite source that depletes in less than seven years, and therefore consideration has been given to use of sub-chronic toxicity values. The >C₈-C₁₀ aliphatic toxicity has been adjusted to represent sub-chronic exposure, resulting in higher HSLs than if based on chronic toxicity. For further information refer to Section 8.2 and Appendix J in Friebel and Nadebaum (2011a).
- (7) The figures in the above table may be multiplied by a factor to account for biodegradation of vapour. A factor of 10 may apply for source depths from 2 m to <4 m or a factor of 100 for source depths of 4 m and deeper. To apply the attenuation factor for vapour degradation, a number of conditions must be satisfied. Firstly the maximum length of the shorter side of the concrete slab and surrounding pavement cannot exceed 15 m, as this would prevent oxygen penetrating to the centre of the slab. Secondly, measurement of oxygen in the subsurface is required to determine the potential for biodegradation. Oxygen must be confirmed to be present at >5% to use these factors.
- (8) For soil texture classification undertaken in accord with AS 1726, the classifications of sand, silt and clay may be applied as coarse, fine with liquid limit <50% and fine with liquid limit >50% respectively, as the underlying properties to develop the HSLs may reasonably be selected to be similar. Where there is uncertainty, either a conservative approach may be adopted or laboratory analysis should be carried out.
- (9) To obtain F1 subtract the sum of BTEX concentrations from the C₆-C₁₀ fraction.
- (10) To obtain F2 subtract naphthalene from the >C₁₀-C₁₆ fraction.

Table 1A(4) Groundwater HSLs for vapour intrusion (mg/L)

CHEMICAL	HSL A & HSL B Low - high density residential			HSL C recreational / open space			HSL D Commercial / industrial			Solubility limit
	2 m to <4 m	4 m to <8 m	8 m+	2 m to <4 m	4 m to <8 m	8 m+	2 m to <4 m	4 m to <8 m	8 m+	
SAND										
Toluene	NL	NL	NL	NL	NL	NL	NL	NL	NL	61
Ethylbenzene	NL	NL	NL	NL	NL	NL	NL	NL	NL	3.9
Xylenes	NL	NL	NL	NL	NL	NL	NL	NL	NL	21
Naphthalene	NL	NL	NL	NL	NL	NL	NL	NL	NL	0.17
Benzene	0.8	0.8	0.9	NL	NL	NL	5	5	5	59
F1 ⁽⁷⁾	1	1	1	NL	NL	NL	6	6	7	9.0
F2 ⁽⁸⁾	1	1	1	NL	NL	NL	NL	NL	NL	3.0
SILT										
Toluene	NL	NL	NL	NL	NL	NL	NL	NL	NL	61
Ethylbenzene	NL	NL	NL	NL	NL	NL	NL	NL	NL	3.9
Xylenes	NL	NL	NL	NL	NL	NL	NL	NL	NL	21
Naphthalene	NL	NL	NL	NL	NL	NL	NL	NL	NL	0.17

	HSL A & HSL B Low - high density residential			HSL C recreational / open space			HSL D Commercial / industrial			
Benzene	4	5	5	NL	NL	NL	30	30	30	59
F1⁽⁷⁾	6	6	6	NL	NL	NL	NL	NL	NL	9.0
F2⁽⁸⁾	NL	NL	NL	NL	NL	NL	NL	NL	NL	3.0
CLAY										
Toluene	NL	NL	NL	NL	NL	NL	NL	NL	NL	61
Ethylbenzene	NL	NL	NL	NL	NL	NL	NL	NL	NL	3.9
Xylenes	NL	NL	NL	NL	NL	NL	NL	NL	NL	21
Naphthalene	NL	NL	NL	NL	NL	NL	NL	NL	NL	0.17
Benzene	5	5	5	NL	NL	NL	30	30	35	59
F1⁽⁷⁾	NL	NL	NL	NL	NL	NL	NL	NL	NL	9.0
F2⁽⁸⁾	NL	NL	NL	NL	NL	NL	NL	NL	NL	3.0

Notes:

- (1) Land use settings are equivalent to those described in Table 1A(1) Footnote 1 and Schedule B7. HSLs for vapour intrusion for high density residential assume residential occupation of the ground floor. If communal car parks or commercial properties occupy the ground floor, HSL D should be used.
- (2) The key limitations of the HSLs are presented in Friebel and Nadebaum (2011d) and should be referred to prior to application.
- (3) Detailed assumptions in the derivation of the HSLs and information on the application of the HSLs are presented in Friebel and Nadebaum (2011a and 2011b).
- (4) The solubility limit is defined as the groundwater concentration at which the water cannot dissolve any more of an individual chemical based on a petroleum mixture. The soil vapour that is in equilibrium with the groundwater will be at its maximum. If the derived groundwater HSL exceeds the water solubility limit, a soil vapour source concentration for a petroleum mixture could not exceed a level that would result in the maximum allowable vapour risk for the given scenario. For these scenarios, no HSL is presented for these chemicals and the HSL is shown as 'not limiting' or 'NL'.
- (5) The figures in the above table may be multiplied by a factor to account for biodegradation of vapour. A factor of 10 may apply for source depths from 2 m to <4 m or a factor of 100 for source depths of 4 m and deeper. To apply the attenuation factor for vapour degradation, a number of conditions must be satisfied. Firstly, the maximum length of the shorter side of the concrete slab and surrounding pavement cannot exceed 15 m, as this would prevent oxygen penetrating to the centre of the slab. Secondly, measurement of oxygen in the subsurface is required to determine the potential for biodegradation. Oxygen must be confirmed to be present at >5% to use these factors.

- (6) For soil texture classification undertaken in accord with AS 1726, the classifications of sand, silt and clay may be applied as coarse, fine with liquid limit <50% and fine with liquid limit >50% respectively, as the underlying properties to develop the HSLs may reasonably be selected to be similar. Where there is uncertainty, either a conservative approach may be adopted or laboratory analysis should be carried out.
- (7) To obtain F1 subtract the sum of BTEX concentrations from the C₆-C₁₀ fraction.
- (8) To obtain F2 subtract naphthalene from the >C₁₀-C₁₆ fraction.

Table 1A(5) Soil vapour HSLs for vapour intrusion (mg/m³)

CHEMICAL	HSL A & HSL B Low - high density residential					HSL C recreational / open space					HSL D Commercial / Industrial				
	0 m to <1 m	1 m to <2 m	2 m to <4 m	4 m to <8 m	8 m+	0 m to <1 m	1 m to <2 m	2 m to <4 m	4 m to <8 m	8 m+	0 m to <1 m	1 m to <2 m	2 m to <4 m	4 m to <8 m	8 m+
SAND															
Toluene	1300	3800	7300	15 000	29 000	NL	NL	NL	NL	NL	4800	16 000	39 000	84 000	NL
Ethylbenzene	330	1100	2200	4300	8700	NL	NL	NL	NL	NL	1300	4600	11 000	25 000	53 000
Xylenes	220	750	1500	3000	6100	NL	NL	NL	NL	NL	840	3,200	8000	18 000	37 000
Naphthalene	0.8	3	6	10	25	410	NL	NL	NL	NL	3	15	35	75	150
Benzene	1	3	6	10	20	360	2400	4700	9500	19 000	4	10	30	65	130
F1 ⁽⁸⁾	180	640	1,300	2600	5300	86 000	NL	NL	NL	NL	680	2800	7000	15 000	32 000
F2 ⁽⁹⁾	130	560	1200	2400	4800	NL	NL	NL	NL	NL	500	2400	NL	NL	NL
SILT															
Toluene	1400	14 000	32 000	69 000	140 000	NL	NL	NL	NL	NL	5700	63 000	NL	NL	NL
Ethylbenzene	380	4200	9700	21 000	43 000	NL	NL	NL	NL	NL	1500	19 000	54 000	NL	NL
Xylenes	260	2900	6800	15 000	30 000	NL	NL	NL	NL	NL	1000	13 000	38 000	NL	NL
Naphthalene	0.9	10	25	60	120	NL	NL	NL	NL	NL	4	50	150	350	750
Benzene	1	10	25	55	110	1800	12 000	24 000	48 000	97 000	4	50	140	320	670
F1 ⁽⁸⁾	210	2600	6000	13 000	26 000	NL	NL	NL	NL	NL	850	11 000	33 000	77 000	160 000

	HSL A & HSL B Low - high density residential					HSL C recreational / open space					HSL D Commercial / Industrial				
F2 ⁽⁹⁾	160	2300	5400	NL	NL	NL	NL	NL	NL	NL	670	NL	NL	NL	NL
CLAY															
Toluene	1600	23 000	53 000	110 000	NL	NL	NL	NL	NL	NL	6500	100 000	NL	NL	NL
Ethylbenzene	420	6800	16 000	35 000	NL	NL	NL	NL	NL	NL	1800	31 000	NL	NL	NL
Xylenes	280	4800	11 000	24 000	50 000	NL	NL	NL	NL	NL	1200	21 000	NL	NL	NL
Naphthalene	1	20	45	95	200	NL	NL	NL	NL	NL	4	85	240	560	1200
Benzene	1	15	40	90	180	3000	20 000	40 000	81 000	160 000	5	80	230	530	1100
F1 ⁽⁸⁾	230	4200	9900	21 000	44 000	NL	NL	NL	NL	NL	1000	19 000	55 000	130 000	270 000
F2 ⁽⁹⁾	180	3,800	NL	NL	NL	NL	NL	NL	NL	NL	800	NL	NL	NL	NL

1. Land use settings are equivalent to those described in Table 1A(1) Footnote 1 and Schedule B7. HSLs for vapour intrusion for high density residential assume residential occupation of the ground floor. If communal car parks or commercial properties occupy the ground floor, HSL D should be used.
2. The key limitations of the HSLs should be referred to prior to application and are presented in Friebel and Nadebaum (2011b and 2011d).
3. Detailed assumptions in the derivation of the HSLs and information on how to apply the HSLs are presented in Friebel and Nadebaum (2011a and 2011b).
4. The maximum possible soil vapour concentrations have been calculated based on vapour pressures of the pure chemicals. Where soil vapour HSLs exceed these values a soil-specific source concentration for a petroleum mixture could not exceed a level that would result in the maximum allowable vapour risk for the given scenario. For these scenarios, no HSL is presented for these chemicals and the HSL is shown as 'not limiting' or 'NL'.
5. Soil vapour HSLs should be compared with measurements taken as laterally close as possible to the soil or groundwater sources of vapour (i.e. within or above vapour sources). Consideration is required of where the sample is taken, the current condition of the site and the likely future condition of the site. Shallow gas measurements in open space (less than 1 m below ground surface) may be subject to influences of weather conditions and moisture.
6. The figures in the above table may be multiplied by a factor to account for biodegradation of vapour. A factor of 10 may apply for source depths from 2 m to <4 m or a factor of 100 for source depths of 4 m and deeper. To apply the attenuation factor for vapour degradation, a number of conditions must be satisfied. Firstly, the maximum length of the shorter side of the concrete slab and surrounding pavement cannot exceed 15 m, as this would prevent oxygen penetrating to the centre of the slab. Secondly, measurement of oxygen in the subsurface is required to determine the potential for biodegradation. Oxygen must be confirmed to be present at >5% to use these factors.
7. For soil texture classification undertaken in accord with AS 1726, the classifications of sand, silt and clay may be applied as coarse, fine with liquid limit <50% and fine with liquid limit >50% respectively as the underlying properties to develop the HSLs may reasonably be selected to be similar. Where there is uncertainty, either a conservative approach may be adopted or laboratory analysis should be carried out.
8. To obtain F1 subtract the sum of BTEX concentrations from the C₆-C₁₀ fraction.

9. To obtain F2 subtract naphthalene from the $>C_{10}$ - C_{16} fraction.

Table 1B(1) Soil-specific added contaminant limits for aged zinc in soil

Zn added contaminant limits (ACL, mg added contaminant/kg)						
Areas of ecological significance						
<i>pH^a</i>	<i>CEC^b (cmol_c/kg)</i>					
	<i>5</i>	<i>10</i>	<i>20</i>	<i>30</i>	<i>40</i>	<i>60</i>
4.0	15	20	20	20	20	20
4.5	20	25	25	25	25	25
5.0	30	40	40	40	40	40
5.5	40	60	60	60	60	60
6.0	50	90	90	90	90	90
6.5	50	90	130	130	130	130
7.0	50	90	150	190	190	190
7.5	50	90	150	210	260	280
Urban residential/public open space¹						
<i>pH^a</i>	<i>CEC^b (cmol_c/kg)</i>					
	<i>5</i>	<i>10</i>	<i>20</i>	<i>30</i>	<i>40</i>	<i>60</i>
4.0	70	85	85	85	85	85
4.5	100	120	120	120	120	120
5.0	130	180	180	180	180	180
5.5	180	270	270	270	270	270
6.0	230	400	400	400	400	400
6.5	230	400	590	590	590	590
7.0	230	400	700	880	880	880
7.5	230	400	700	960	1200	1300
Commercial/industrial						
<i>pH^a</i>	<i>CEC^b (cmol_c/kg)</i>					
	<i>5</i>	<i>10</i>	<i>20</i>	<i>30</i>	<i>40</i>	<i>60</i>
4.0	110	130	130	130	130	130
4.5	150	190	190	190	190	190
5.0	210	290	290	290	290	290
5.5	280	420	420	420	420	420
6.0	360	620	620	620	620	620
6.5	360	620	920	920	920	920
7.0	360	620	1100	1400	1400	1400
7.5	360	620	1100	1500	1900	2000

1. Urban residential/public open space is broadly equivalent to the HIL A, HIL B and HIL C land use scenarios in Table 1A(1) Footnote 1 and as described in Schedule B7.

2. Aged values apply to contamination present in soil for at least two years. For fresh contamination refer to Schedule B5c.

3. The EIL is calculated from summing the ACL and the ABC.

a = pH measured using the CaCl₂ method (Rayment & Higginson 1992).

b = CEC measured using the silver thiourea method (Chabra et al. 1972).

Table 1B(2) Soil-specific added contaminant limits for aged copper in soils

Cu added contaminant limits (ACL, mg added contaminant/kg)					
Areas of ecological significance					
<i>CEC (cmol_e/kg)^a based</i>					
<i>5</i>	<i>10</i>	<i>20</i>	<i>30</i>	<i>40</i>	<i>60</i>
30	65	70	70	75	80
<i>pH^b based</i>					
<i>4.5</i>	<i>5.5</i>	<i>6</i>	<i>6.5</i>	<i>7.5</i>	<i>8.0</i>
20	45	65	90	190	270
Urban residential/public open space¹					
<i>CEC (cmol_e/kg)^a based</i>					
<i>5</i>	<i>10</i>	<i>20</i>	<i>30</i>	<i>40</i>	<i>60</i>
95	190	210	220	220	230
<i>pH^b based</i>					
<i>4.5</i>	<i>5.5</i>	<i>6</i>	<i>6.5</i>	<i>7.5</i>	<i>8.0</i>
60	130	190	280	560	800
Commercial/industrial					
<i>CEC (cmol_e/kg)^a based</i>					
<i>5</i>	<i>10</i>	<i>20</i>	<i>30</i>	<i>40</i>	<i>60</i>
140	280	300	320	330	340
<i>pH^b based</i>					
<i>4.5</i>	<i>5.5</i>	<i>6</i>	<i>6.5</i>	<i>7.5</i>	<i>8.0</i>
85	190	280	400	830	1200

Notes:

1. Urban residential/public open space is broadly equivalent to the HIL A, HIL B and HIL C land use scenarios in Table 1A(1) Footnote 1 and as described in Schedule B7.
2. The lower of the CEC or the pH-based ACLs for the land use and soil conditions is the ACL to be used.
3. Aged values apply to contamination present in soil for at least two years. For fresh contamination refer to Schedule B5c.
4. The EIL is calculated from summing the ACL and the ABC.

a = CEC measured using the silver thiourea method (Chabra et al. 1972).

b = pH measured using the CaCl₂ method (Rayment & Higginson 1992).

Table 1B(3) Soil-specific added contaminant limits for aged chromium III and nickel in soil

CHEMICAL	Clay content (% clay)	Added contaminant limits (mg added contaminant/kg) for various land uses		
		Areas of ecological significance	Urban residential and public open space	Commercial and industrial
Chromium III	1	60	190	310
	2.5	80	250	420
	5	100	320	530
	≥10	130	400	660
Nickel	CEC ^a (cmol _c /kg)	Areas of ecological significance	Urban residential and public open space ¹	Commercial and industrial
	5	5	30	55
	10	30	170	290
	20	45	270	460
	30	60	350	600
	40	70	420	730
	60	95	560	960

Notes:

1. Urban residential/public open space is broadly equivalent to the HIL A, HIL B and HIL C land use scenarios in Table 1A(1) Footnote 1 and as described in Schedule B7.
 2. Aged values apply to contamination present in soil for at least two years. For fresh contamination refer to Schedule B5c.
 3. The EIL is calculated from summing the ACL and the ABC.
- a = CEC measured using the silver thiourea method (Chabra et al. 1972).

Table 1B(4) Generic added contaminant limits for lead in soils irrespective of their physicochemical properties

CHEMICAL	Pb added contaminant limit (ACL, mg added contaminant/kg) for various land uses		
	Areas of ecological significance	Urban residential and public open space ¹	Commercial and industrial
Lead	470	1100	1800

Notes:

1. Urban residential/public open space is broadly equivalent to the HIL A, HIL B and HIL C land use scenarios in Table 1A(1) Footnote 1 and as described in Schedule B7.
2. Aged values are applicable to lead contamination present in soil for at least two years. For fresh contamination refer to Schedule B5c.
3. The EIL is calculated from summing the ACL and the ABC.

Table 1B(5) Generic EILs for aged As, fresh DDT and fresh naphthalene in soils irrespective of their physicochemical properties

CHEMICAL	Ecological Investigation Levels (mg total contaminant/kg)		
	Areas of ecological significance	Urban residential and public open space ¹	Commercial and industrial
Arsenic ²	40	100	160
DDT ³	3	180	640
Naphthalene ³	10	170	370

Notes:

1. Urban residential/public open space is broadly equivalent to the HIL-A, HIL-B and HIL-C land use scenarios in Table 1A(1) Footnote 1 and as described in Schedule B7.
2. Aged values are applicable to arsenic contamination present in soil for at least two years. For fresh contamination refer to Schedule B5c.
3. Insufficient data was available to calculate aged values for DDT and naphthalene, consequently the values for fresh contamination should be used.
4. Insufficient data was available to calculate ACLs for As, DDT and naphthalene. The EIL should be taken directly from Table 1B(5).

Table 1B(6) ESLs for TPH fractions F1 – F4, BTEX and benzo(a)pyrene in soil

CHEMICAL	Soil texture	ESLs (mg/kg dry soil)		
		Areas of ecological significance	Urban residential and public open space	Commercial and industrial
F1 C ₆ -C ₁₀		125*	180*	215*
F2 >C ₁₀ -C ₁₆	<i>Coarse/ Fine</i>	25*	120*	170*
F3 >C ₁₆ -C ₃₄	<i>Coarse</i>	-	300	1700
	<i>Fine</i>	-	1300	2500
F4 >C ₃₄ -C ₄₀	<i>Coarse</i>	-	2800	3300
	<i>Fine</i>	-	5600	6600
Benzene	<i>Coarse</i>	10	50	75
	<i>Fine</i>	10	65	95
Toluene	<i>Coarse</i>	10	85	135
	<i>Fine</i>	65	105	135
Ethylbenzene	<i>Coarse</i>	1.5	70	165
	<i>Fine</i>	40	125	185
Xylenes	<i>Coarse</i>	10	105	180
	<i>Fine</i>	1.6	45	95
Benzo(a)pyrene	<i>Coarse</i>	0.7	0.7	0.7
	<i>Fine</i>	0.7	0.7	0.7

Notes:

- (1) ESLs are of low reliability except where indicated by * which indicates that the ESL is of moderate reliability.
- (2) ‘-’ indicates that insufficient data was available to derive a value.
- (3) To obtain F1, subtract the sum of BTEX concentrations from C₆-C₁₀ fraction and subtract naphthalene from >C₁₀-C₁₆ to obtain F2.

Table 1 B(7) Management Limits for TPH fractions F1–F4 in soil

TPH fraction	Soil texture	Management Limits ¹ (mg/kg dry soil)	
		Residential, parkland and public open space	Commercial and industrial
F1² C ₆ - C ₁₀	<i>Coarse</i>	700	700
	<i>Fine</i>	800	800
F2² >C ₁₀ -C ₁₆	<i>Coarse</i>	1000	1000
	<i>Fine</i>	1000	1000
F3 >C ₁₆ -C ₃₄	<i>Coarse</i>	2500	3500
	<i>Fine</i>	3500	5000
F4 >C ₃₄ -C ₄₀	<i>Coarse</i>	10 000	10 000
	<i>Fine</i>	10 000	10 000

¹ Management limits are applied after consideration of relevant ESLs and HSLs

² Separate management limits for BTEX and naphthalene are not available hence these should not be subtracted from the relevant fractions to obtain F1 and F2.

Table 1C Groundwater Investigation Levels (GILs)

Substance	Groundwater Investigation Levels		
	Fresh Waters ^A	Marine Waters ^A	Drinking Water ^B
	(µg/L)	(µg/L)	(mg/L)
Metals and Metalloids			
Aluminium, Al pH>6.5	55	-	-
Antimony	-	-	0.003
Arsenic	24 as As(III) 13 as As(V)	-	0.01
Barium	-	-	2
Beryllium	-	-	0.06
Boron	370 ^C	-	4
Cadmium H	0.2	0.7 ^D	0.002
Chromium, Cr (III) H	-	27	-
Chromium, Cr (VI)	1 ^C	4.4	0.05
Cobalt	-	1	-
Copper H	1.4	1.3	2
Iron, (Total)	-	-	-
Lead H	3.4	4.4	0.01
Manganese	1900 ^C	-	0.5
Mercury (Total)	0.06 ^D	0.1 ^D	0.001
Molybdenum	-	-	0.05
Nickel H	11	7	0.02
Selenium (Total)	5 ^D	-	0.01
Silver	0.05	1.4	0.1
Tributyl tin (as Sn)	-	0.006 ^C	-
Tributyl tin oxide	-	-	0.001
Uranium	-	-	0.017
Vanadium	-	100	-
Zinc H	8 ^C	15 ^C	-
Non-metallic Inorganics			
Ammonia ^E (as NH ₃ -N at pH 8)	900 ^C	910	-
Bromate	-	-	0.02
Chloride	-	-	-
Cyanide (as un-ionised Cn)	7	4	0.08
Fluoride	-	-	1.5
Hydrogen sulphide (un-ionised H ₂ S measured as S)	1	-	-
Iodide	-	-	0.5

Substance	Groundwater Investigation Levels		
	Fresh Waters ^A	Marine Waters ^A	Drinking Water ^B
	(µg/L)	(µg/L)	(mg/L)
Nitrate (as NO ₃)	refer to guideline	refer to guideline	50
Nitrite (as NO ₂)	refer to guideline	refer to guideline	3
Nitrogen	refer to guideline	refer to guideline	-
Phosphorus	refer to guideline	refer to guideline	-
Sulphate (as SO ₄)	-	-	500
Organic alcohols/other organics			
Ethanol	1400	-	-
Ethylenediamine tetra-acetic acid (EDTA)	-	-	0.25
Formaldehyde	-	-	0.5
Nitrilotriacetic acid	-	-	0.2
Anilines			
Aniline	8	-	-
2,4-Dichloroaniline	7	-	-
3,4-Dichloroaniline	3	150	-
Chlorinated Alkanes			
Dichloromethane	-	-	0.004
Trichloromethane (chloroform)	-	-	0.003
Trihalomethanes (total)	-	-	0.25
Tetrachloromethane (carbon tetrachloride)	-	-	0.003
1,2-Dichloroethane	-	-	0.003
1,1,2-Trichloroethane	6500	1900	-
Hexachloroethane	290 ^D	-	-
Chlorinated Alkenes			
Chloroethene (vinyl chloride)	-	-	0.0003
1,1-Dichloroethene	-	-	0.03
1,2-Dichloroethene	-	-	0.06
Tetrachloroethene (PCE) (Perchloroethene)	-	-	0.05
Chlorinated Benzenes			
Chlorobenzene	-	-	0.3
1,2- Dichlorobenzene	160	-	1.5
1,3- Dichlorobenzene	260	-	-

Substance	Groundwater Investigation Levels		
	Fresh Waters ^A	Marine Waters ^A	Drinking Water ^B
	(µg/L)	(µg/L)	(mg/L)
1,4- Dichlorobenzene	60	-	0.04
1,2,3- Trichlorobenzene	3 ^D	-	0.03 for individual or total trichlorobenzenes
1,2,4- Trichlorobenzene	85 ^D	20 ^D	
1,3,5-Trichlorobenzene	-	-	
Polychlorinated Biphenyls (PCBs)			
Aroclor 1242	0.3 ^D	-	-
Aroclor 1254	0.01 ^D	-	-
Other Chlorinated Compounds			
Epichlorohydrin	-	-	0.1
Hexachlorobutadiene	-	-	0.0007
Monochloramine	-	-	3
Monocyclic Aromatic Hydrocarbons			
Benzene	950	500 ^C	0.001
Toluene	-	-	0.8
Ethylbenzene	-	-	0.3
Xylenes	350 (as o-xylene) 200 (as p-xylene)	-	0.6
Styrene (Vinyl benzene)	-	-	0.03
Polycyclic Aromatic Hydrocarbons (PAHs)			
Naphthalene	16	50 ^C	-
Benzo[a]pyrene	-	-	0.00001
Phenols			
Phenol	320	400	-
2-Chlorophenol	340 ^C	-	0.3
4-Chlorophenol	220	-	-
2,4-Dichlorophenol	120	-	0.2
2,4,6-Trichlorophenol	3 ^D	-	0.02
2,3,4,6-Tetrachlorophenol	10 ^D	-	-
Pentachlorophenol	3.6 ^D	11 ^D	0.01
2,4-Dinitrophenol	45	-	-
Phthalates			
Dimethylphthalate	3700	-	-
Diethylphthalate	1000	-	-
Dibutylphthalate	10 ^D	-	-
Di(2-ethylhexyl) phthalate	-	-	0.01

Substance	Groundwater Investigation Levels		
	Fresh Waters ^A	Marine Waters ^A	Drinking Water ^B
	(µg/L)	(µg/L)	(mg/L)
Pesticides			
Acephate	-	-	0.008
Aldicarb	-	-	0.004
Aldrin plus Dieldrin	-	-	0.0003
Ametryn	-	-	0.07
Amitraz	-	-	0.009
Amitrole	-	-	0.0009
Asulam	-	-	0.07
Atrazine	13	-	0.02
Azinphos-methyl	-	-	0.03
Benomyl	-	-	0.09
Bentazone	-	-	0.4
Bioresmethrin	-	-	0.1
Bromacil	-	-	0.4
Bromoxynil	-	-	0.01
Captan	-	-	0.4
Carbaryl	-	-	0.03
Carbendazim (Thiophanate-methyl)	-	-	0.09
Carbofuran	0.06	-	0.01
Carboxin	-	-	0.3
Carfentrazone-ethyl	-	-	0.1
Chlorantraniliprole	-	-	6
Chlordane	0.03 ^D	-	0.002
Chlorfenvinphos	-	-	0.002
Chlorothalonil	-	-	0.05
Chlorpyrifos	0.01 ^D	0.009 ^D	0.01
Chlorsulfuron	-	-	0.2
Clopyralid	-	-	2
Cyfluthrin, Beta-cyfluthrin	-	-	0.05
Cypermethrin isomers	-	-	0.2
Cyprodinil	-	-	0.09
1,3-Dichloropropene	-	-	0.1
2,2-DPA	-	-	0.5
2,4-D [2,4-dichlorophenoxy acetic acid]	280	-	0.03
DDT	0.006 ^D	-	0.009
Deltramethrin	-	-	0.04

Substance	Groundwater Investigation Levels		
	Fresh Waters ^A	Marine Waters ^A	Drinking Water ^B
	(µg/L)	(µg/L)	(mg/L)
Diazinon	0.01	-	0.004
Dicamba	-	-	0.1
Dichloroprop	-	-	0.1
Dichlorvos	-	-	0.005
Dicofol	-	-	0.004
Diclofop-methyl	-	-	0.005
Dieldrin plus Aldrin	-	-	0.0003
Diflubenzuron	-	-	0.07
Dimethoate	0.15	-	0.007
Diquat	1.4	-	0.007
Disulfoton	-	-	0.004
Diuron	-	-	0.02
Endosulfan	0.03 ^D	0.005 ^D	0.02
Endothal	-	-	0.1
Endrin	0.01 ^D	0.004 ^D	-
EPTC	-	-	0.3
Esfenvalerate	-	-	0.03
Ethion	-	-	0.004
Ethoprophos	-	-	0.001
Etridiazole	-	-	0.1
Fenamiphos	-	-	0.0005
Fenarimol	-	-	0.04
Fenitrothion	0.2	-	0.007
Fenthion	-	-	0.007
Fenvalerate	-	-	0.06
Fipronil	-	-	0.0007
Flamprop-methyl	-	-	0.004
Fluometuron	-	-	0.07
Fluproponate	-	-	0.009
Glyphosate	370	-	1
Haloxifop	-	-	0.001
Heptachlor	0.01 ^D	-	-
Heptachlor epoxide	-	-	0.0003
Hexazinone	-	-	0.4
Imazapyr	-	-	9
Iprodione	-	-	0.1
Lindane (γ-HCH)	0.2	-	0.01

Substance	Groundwater Investigation Levels		
	Fresh Waters ^A	Marine Waters ^A	Drinking Water ^B
	(µg/L)	(µg/L)	(mg/L)
Malathion	0.05	-	0.07
Mancozeb (as ETU, ethylene thiourea)	-	-	0.009
MCPA	-	-	0.04
Metaldehyde	-	-	0.02
Metham (as methylisothiocyanate, MITC)	-	-	0.001
Methidathion	-	-	0.006
Methiocarb	-	-	0.007
Methomyl	3.5	-	0.02
Methyl bromide	-	-	0.001
Metiram (as ETU, ethylene thiourea)	-	-	0.009
Metolachlor/s–Metolachlor	-	-	0.30
Metribuzin	-	-	0.07
Metsulfuron-methyl	-	-	0.04
Mevinphos	-	-	0.006
Molinate	3.4	-	0.004
Napropamide	-	-	0.4
Nicarbazin	-	-	1
Norflurazon	-	-	0.05
Omethoate	-	-	0.001
Oryzalin	-	-	0.4
Oxamyl	-	-	0.007
Paraquat	-	-	0.02
Parathion	0.004 ^C	-	0.02
Parathion methyl	-	-	0.0007
Pebulate	-	-	0.03
Pendimethalin	-	-	0.4
Pentachlorophenol	-	-	0.01
Permethrin	-	-	0.2
Picloram	-	-	0.30
Piperonyl butoxide	-	-	0.6
Pirimicarb	-	-	0.007
Pirimiphos methyl	-	-	0.09
Polihexanide	-	-	0.7
Profenofos	-	-	0.0003

Substance	Groundwater Investigation Levels		
	Fresh Waters ^A	Marine Waters ^A	Drinking Water ^B
	(µg/L)	(µg/L)	(mg/L)
Propachlor	-	-	0.07
Propanil	-	-	0.7
Propargite	-	-	0.007
Proparazine	-	-	0.05
Propiconazole	-	-	0.1
Propyzamide	-	-	0.07
Pyrasulfatole	-	-	0.04
Pyrazophos	-	-	0.02
Pyroxsulam	-	-	4
Quintozene	-	-	0.03
Simazine	3.2	-	0.02
Spirotetramat	-	-	0.2
Sulprofos	-	-	0.01
2,4,5-T	36	-	0.1
Tebuthiuron	2.2	-	-
Temephos	-	0.05 ^D	0.4
Terbacil	-	-	0.2
Terbufos	-	-	0.0009
Terbuthylazine	-	-	0.01
Terbutryn	-	-	0.4
Thiobencarb	2.8	-	0.04
Thiometon	-	-	0.004
Thiram	0.01	-	0.007
Toltrazuril	-	-	0.004
Toxafene	0.1 ^D	-	-
Triadimefon	-	-	0.09
Trichlorfon	-	-	0.007
Triclopyr	-	-	0.02
Trifluralin	2.6 ^D	-	0.09
Vernolate	-	-	0.04
Surfactants			
Linear alkylbenzene sulfonates (LAS)	280	-	-
Alcohol ethoxylated sulfate (AES)	650	-	-
Alcohol ethoxylated surfactants (AE)	140	-	-

Substance	Groundwater Investigation Levels		
	Fresh Waters ^A	Marine Waters ^A	Drinking Water ^B
	(µg/L)	(µg/L)	(mg/L)

- A Investigation levels apply to typical slightly-moderately disturbed systems. See ANZECC & ARMCANZ (2000) for guidance on applying these levels to different ecosystem conditions.
- B Investigation levels are taken from the health values of the Australian Drinking Water Guidelines (NHMRC 2011).
- C Figure may not protect key species from chronic toxicity, refer to ANZECC & ARMCANZ (2000) for further guidance.
- D Chemical for which possible bioaccumulation and secondary poisoning effects should be considered, refer to ANZECC & ARMCANZ (2000) for further guidance.
- E For changes in GIL with pH refer to ANZECC & ARMCANZ (2000) for further guidance.
- H Values have been calculated using a hardness of 30 mg/L CaCO₃ refer to ANZECC & ARMCANZ (2000) for further guidance on recalculating for site-specific hardness.

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8 Glossary

Added contaminant limit (ACL) is the added concentration of a contaminant above which further appropriate investigation and evaluation of the impact on ecological values will be required. ACL values are generated in the process of deriving ecological investigation levels (EILs).

Ambient background concentration (ABC) of a contaminant is the soil concentration in a specified locality that is the sum of the naturally occurring background and the contaminant levels that have been introduced from diffuse or non-point sources by general anthropogenic activity not attributable to industrial, commercial or agricultural activities.

An **area of ecological significance** is one where the planning provisions or land use designation is for the primary intention of conserving and protecting the natural environment. This would include national parks, state parks, and wilderness areas and designated conservation areas.

Asbestos fines (AF) includes free fibres of asbestos, small fibre bundles and fragments of bonded ACM that pass a 7 mm x 7 mm sieve.

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

Bonded asbestos-cement-material (bonded ACM) comprises bonded asbestos containing material which is in sound condition (although possibly broken or fragmented), and is restricted to material that cannot pass a 7 mm x 7 mm sieve. This sieve size is selected as it approximates the thickness of common asbestos cement sheeting and for fragments to be smaller than this would imply a high degree of damage and potential for fibre release.

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

Contamination means the condition of land or water where any chemical substance or waste has been added as a direct or indirect result of human activity at above background level and represents, or potentially represents, an adverse health or environmental impact.

Ecological investigation levels (EILs) are the concentrations of contaminants above which further appropriate investigation and evaluation will be required. EILs depend on specific soil physicochemical properties and land use scenarios and generally apply to the top 2 m of soil. EILs may also be referred to as soil quality guidelines in Schedules B5b and B5c.

Ecological screening levels (ESLs) for petroleum hydrocarbons are the concentrations above which further appropriate investigation and evaluation will be required. ESLs broadly apply to coarse- and fine-grained soils and various land uses. They are generally applicable to the top 2 m of soil.

Environmental value is a value or use of the environment which is conducive to public benefit, welfare, safety or health and which requires protection from the effects of pollution, waste discharge and deposits.

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

Fibrous asbestos (FA) includes loose fibrous material such as insulation products, severely weathered cement-bonded asbestos sheeting and damaged low density board (up to 70% asbestos in calcium silicate). For the purposes of site assessment, FA includes any asbestos-containing-material (ACM) that is easily powdered or made pasty with clear separation of asbestos fibres by moderate hand pressure.

Groundwater investigation level (GIL) is the concentration of a groundwater parameter at which further investigation (point of extraction) or a response (point of use) is required. Includes Australian water quality guidelines, drinking water guidelines, guidelines for managing risk in recreational water criteria and site-specific derived criteria.

Health investigation levels (HILs) are the concentrations of a contaminant above which further appropriate investigation and evaluation will be required. HILs are generic to all soil types and generally apply to the top 3 m of soil.

Health risk assessment (HRA) is the process of estimating the potential impact of a chemical, biological or physical agent on a specified human population system under a specific set of conditions.

Health screening levels (HSLs) for petroleum hydrocarbons are the concentrations above which further appropriate investigation and evaluation will be required. HSLs depend on physicochemical properties of soil, as these affect hydrocarbon vapour movement in soil, and the characteristics of building structures. HSLs apply to different soil types, land uses and depths below surface to >4 m and have a range of limitations.

Investigation levels and screening levels are the concentrations of a contaminant above which further appropriate investigation and evaluation will be required. Investigation and screening levels provide the basis of Tier 1 risk assessment.

Petroleum hydrocarbon '**management limits**' are limited to petroleum hydrocarbon compounds. They are maximum values that should remain in a site following evaluation of human health and ecological risks and risks to groundwater resources and apply to all soil depths based on site-specific considerations. These limits are to consider the formation of light non aqueous phase liquids, fire and explosion risks and damage to buried infrastructure.

Multiple-lines-of-evidence approach is the process for evaluating and integrating information from different sources of data and uses best professional judgement to assess the consistency and plausibility of the conclusions which can be drawn.

Risk means the probability in a certain timeframe that an adverse outcome will occur in a person, a group of people, plants, animals and/or the ecology of a specified area that is exposed to a particular dose or concentration of a chemical substance, that is, it depends on both the level of toxicity of the chemical substance and the level of exposure to it.

Risk assessment is the process of estimating the potential impact of a chemical, physical, microbiological or psychosocial hazard on a specified human population or ecological system under a specific set of conditions and for a certain timeframe.

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.

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

A **Tier 1 assessment** is a risk-based analysis comparing site data with investigation and screening levels for various land uses to determine the need for further assessment or development of an appropriate management strategy.

9 Shortened forms

ABC	ambient background concentration
ACL	added contaminant limit
ACM	asbestos-containing-material
ADI	acceptable daily intake
ADWG	<i>Australian Drinking Water Guidelines</i>
AF	asbestos fines
AM	arithmetic mean
AS	Australian Standard
As	Arsenic
AWQG	<i>Australian Water Quality Guidelines 2000</i>
B(a)P	benzo(a)pyrene
Bonded ACM	bonded asbestos-containing-material
BTEX	benzene, toluene, ethylbenzene and xylenes
CCME	Canadian Council of the Ministers of the Environment
CEC	cation exchange capacity
CRC CARE	Cooperative Research Centre for Contamination Assessment and Remediation of the Environment
CSIRO	Commonwealth Scientific and Industrial Research Organisation
Cr III	Chromium
CSM	Conceptual Site Model
Cu	Copper
CWS PHC	<i>Canada Wide Standard for Petroleum Hydrocarbons (PHCs) in Soil</i>
DDT	dichlorodiphenyltrichloroethane
DQO	data quality objective
DSI	detailed site investigation
EC₃₀	effective concentration 30%
EIL	ecological investigation level
ESL	ecological screening level
FA	fibrous asbestos
GC-MS	gas chromatography-mass spectrometry
GIL	groundwater investigation level
GM	geometric mean
GMRRW	<i>Guidelines for Managing Risk in Recreational Water</i>
HIL	health investigation level
HSL	health screening level

IEUBK	integrated exposure uptake biokinetic model (for lead)
ISQG	<i>Interim Sediment Quality Guideline</i>
LNAPL	light non-aqueous phase liquid
LOEC	lowest observed effect concentration
MTBE	Methyl tert-butyl ether
N/A	not applicable
NATA	National Association of Testing Authorities
Ni	Nickel
NL	not limiting
OCP	organochlorine pesticide
PAH	polycyclic aromatic hydrocarbon
Pb	Lead
PCB	polychlorinated biphenyl
PCE	perchloroethene
PSI	preliminary site investigation
RfD	reference dose
SAQP	Sampling and Analysis Quality Plan
SD	standard deviation
SSD	species sensitivity distribution
TCE	tetrachlorethene
TDI	tolerable daily intake
TDS	total dissolved solids
TEF	toxicity equivalence factor
TEQ	toxicity equivalent quotient
TPH	total petroleum hydrocarbons
TRH	total recoverable hydrocarbons
UCL	upper confidence limit
US EPA	United States Environmental Protection Agency
VOCC	volatile organic chlorinated compound
WA DoH	Western Australian Department of Health
WHO	World Health Organization
WHS	work health and safety
Zn	Zinc