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report

**Health screening levels for petroleum
hydrocarbons in soil and groundwater**
Summary

E. Friebel and P. Nadebaum



CRC for Contamination Assessment and Remediation of the Environment

Technical Report no. 10

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GHD Pty Ltd

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Preamble

CRC CARE has undertaken the development of health-based screening levels (HSLs) for petroleum hydrocarbons to address an identified need for consistent human health risk assessment of petroleum hydrocarbon contamination in Australian conditions. The HSLs represent the best collective view of the available science and application of Australian approaches on selection of health criteria and exposure parameters. The document underwent several international peer reviews by experts in the United States, Canada and Australia. Given the innovative nature of the work, CRC CARE will monitor national and international developments, and publish updates as and when necessary.

The HSLs and the underlying methodology may be used for health risk assessment purposes in the context of the wider site assessment framework for petroleum hydrocarbon contamination provided in the Assessment of Site Contamination NEPM as varied. It should be noted that the HSLs were derived through the consideration of health effects only, with particular emphasis on the vapour exposure pathway. Other considerations such as ecological risk, aesthetics, the presence of free phase product and explosive/fire risk will need to be assessed separately, as they are not addressed by the HSLs.

It is strongly recommended that the HSL technical development document and the associated documents (*Part 2: Application document, Part 3: Sensitivity assessment and Part 4: Extension model*) are referred to for the key assumptions for the derivation of the HSLs, and for their application and limitations on their use.

The assessment of contamination using health-based screening criteria and investigation thresholds is a complex matter. While every effort has been made to identify and assess the significant risks to human health associated with petroleum hydrocarbon contamination, it is strongly recommended that assessments are carried out by appropriately qualified and experienced persons (who understand the context, requirements and limitations of such use), in consultation with the relevant jurisdiction.

Many of the assumptions that underlie the HSL values involve policy decisions. It is possible that future reviews may lead to changes in the assumptions and the values of the HSLs. It is, therefore, important to check the CRC CARE website for relevant updates at the time of the assessment.

1. Introduction

1.1 Project background

The Cooperative Research Centre for Contamination Assessment and Remediation of the Environment (CRC CARE) includes in its research program the subprogram 'Risk Characterisation and Communication'. This subprogram includes the objective of preparing health screening levels (HSLs) for hydrocarbons in soil and groundwater. This summary presents the derived petroleum HSLs for Australian assessments.

The HSLs were developed with the view that they would be considered in the Variation of the *National Environment Protection (Assessment of Site Contamination) Measure, 1999* (NEPM).

The attached tables contain a summary of the derived HSLs for petroleum hydrocarbons for different land uses and media (soil vapour, groundwater and soil). The accompanying text in this document and table notes must be read in conjunction with the HSLs which highlight the key limitations of the HSLs. The assumptions and methodology used to derive the HSLs are the outcome of extensive discussion within the Australian regulator, industry and consultant community.

Further information is provided in Section 2 on the application of the HSLs.

1.2 References

The detailed methodologies and assumptions used in the development and application of HSLs for petroleum hydrocarbons are presented in the following documents:

- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 1: Technical development document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.
- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 2: Application document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.

It is recommended that these documents be referred to for technical details on the key assumptions and limitations of the derived screening levels and on their application and use. Section 2 is a summary of the key considerations in the application of the HSLs.

Additional references important to the application of the HSLs are:

- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 3: Sensitivity assessment*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.
- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 4: Extension model*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.

- Davis, GB, Patterson, BM & Trefry, MG 2009, *Biodegradation of petroleum hydrocarbon vapours*, CRC CARE Technical Report no. 12, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.
- Davis, GB, Wright, J & Patterson, BM 2009, *Field assessment of vapours*, CRC CARE Technical Report no. 13, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.

2. Application of HSLs

HSLs have been derived for soil vapour, groundwater and soil for petroleum hydrocarbons (see tables at the end of this document).

The approach taken in the development of the HSLs has sought to set a combination of assumptions and parameters that correspond to the reasonable maximum exposure that can be expected, to be protective of human health for a range of scenarios. Users of the screening levels should consider whether their site situation falls within the range of conditions that has been assumed; if this is not the case the HSLs may not be protective and a more detailed consideration of the site-specific situation should be carried out.

The HSLs should only be directly applied to petroleum contamination sources and not to pure compound solvents, as solubility limits incorporated into the HSLs were derived based on typical compositions of petrol and diesel. The HSLs may be applied to other fuel types (e.g. kerosene, aviation fuel and fuel oil); however, confirmation of aliphatic/aromatic speciation (80:20) is required to confirm their applicability.

An application checklist is presented in Appendix A of the HSL application document (Friebel & Nadebaum 2011 – Part 2) and should be referred to when applying the HSLs.

There are a number of important considerations when applying the HSLs; some are discussed in this summary document. The HSL application document (Friebel & Nadebaum 2011 – Part 2) should be referred to for detailed information.

Maximum soil vapour from soil and groundwater sources

- HSLs for vapour intrusion from soil (Table 3) and groundwater (Table 2) sources are limited by estimates of chemical solubilities from petroleum mixtures. Soil and groundwater HSLs have been based on the three-phase equilibrium theory, and the soil vapour is limited by the maximum solubility limit of the chemical in the pore water phase or groundwater. The soil saturation concentration (C_{sat}) is the calculated bulk soil concentration where pore water is at the solubility limit and soil vapour is at its maximum. Where it is determined that a soil concentration greater than C_{sat} (or a groundwater concentration greater than solubility limit) is the calculated HSL, this means that the soil vapour in the soil or above groundwater cannot result in an unacceptable vapour risk for that given scenario, and hence no HSL is presented. In Tables 2 and 3, this is denoted by 'NL'.
- For soil vapour HSLs (Table 1), maximum soil vapour concentrations have been based on vapour pressures of individual chemicals, and the ideal gas law. Soil vapour HSLs that exceed the maximums cannot result in an unacceptable vapour risk for that given scenario, and hence no HSL is presented. In Table 1, this is denoted by 'NL'.

Appropriate sampling

- When considering the appropriate media for sampling, consideration needs to be given to accuracy and representativeness of the measurement, and needs to be considered on a site-by-site basis.

- Soil vapour measurements may be considered to be a more accurate assessment of vapour risks than measurements from bulk soil or groundwater. However measurement of soil vapour is not always appropriate or possible, such as during validation of excavation pits prior to backfilling.
- Other issues may arise for soil vapour measurements in redevelopment sites where the proposed building does not exist and the source in question is near surface where soil vapour measurements may be subject to atmospheric and meteorological influence.

Appropriate land use and exposure scenarios

- The selected land use must be considered. For example, HSLs derived for commercial/industrial land use (HSL-D) assume adults are exposed during the work day, and cannot be applied to land use settings where there may be prolonged exposure to more sensitive receptors, such as children in schools or childcare centres, inpatients or residents in health care facilities, nursing homes or hospitals or other similar land use that may be permitted under a commercial or industrial zoning.
- Residential use has been subdivided into low-density (HSL-A, access to soils) and high-density (HSL-B, limited access to soils). Where there is access to surface soils, HSLs for direct contact in addition to HSLs based on vapour need to be considered (Table 4). Where access to soils is unlikely, such as soils at depth, only HSLs based on vapour intrusion need be considered.
- The land use setting for vapour intrusion into high-density residential building is based on occupation of ground floor. If residents occupy ground floor apartments, HSL-B should be used. If the ground floor consists of commercial properties, HSL-D should be used. If the building contains a communal basement car park, commercial use (HSL-D) should be applied.
- The HSLs only consider direct contact with soils and vapour intrusion. Consideration has not been given to the health risk associated with extraction and use of groundwater. If a groundwater bore is impacted by a petroleum source the HSLs do not consider the contribution of risk from this exposure route, and a site-specific risk assessment on the combined risk scenario should be considered.

Appropriate soil type

- The HSLs assume a homogeneous soil type and have been based on the US soil texture classification system. The soil type with the largest component within a vertical profile should be used when assessing contaminated sites. The sand/silt/clay content, as well as moisture content and air porosity, needs to be assessed and the appropriate soil type category carefully selected. The texture sub-categories have been grouped based on saturation porosity. The categories for soil are:
 - Sand (sand, sandy clay, sandy clay loam, sandy loam, loamy sand, loam, sandy silt and silty sand)
 - Silt (silt, silty clay and silty clay loam)
 - Clay (clay, clay loam and silt loam).

- For soil assessment (texture classification) undertaken in accord with AS 1726 the classifications of sand, silt and clay may be applied as coarse, fine with liquid limit less than 50%, and fine with liquid limit greater than 50% respectively, as the underlying properties used to develop the HSLs may reasonably be selected to be similar. Where there is uncertainty, laboratory analysis should be carried out to get detailed particle size analysis, soil texture sub class, and liquid limit. Saturation porosity may also be obtained as this parameter is used for site-specific (Tier 2 and Tier 3) assessment.
- If the soil type varies with depth or location, this needs to be considered. For example, the backfill associated with underground storage tanks (USTs) that have been removed and cleaned up can contain backfill material different to the in-situ soil. The soil type overlying contamination is more important than the soil type of the contamination source itself. Another example is that the geology on one part of the site (sand) may be different to another part of the site (clay), which would pose different levels of risk for the same land use scenario.

Contamination sources

- As previously mentioned, soil and groundwater HSLs for vapour intrusion have been developed based on typical petroleum mixtures and consider the solubility limits of petroleum mixtures. HSLs cannot be applied to non-petroleum sources such as pure solvents or gasworks wastes, where solubility limits are much higher. To assess chemicals from non-petroleum sources the appropriate method is described in the application document (Friebel & Nadebaum 2011 – Part 2).
- The 95% upper confidence limit of the arithmetic mean (95%UCL) soil concentration may be used to compare the HSLs; however, the sample concentrations used for the calculation of the mean must be relevant to the area of the property where the exposure is likely to occur. This is particularly important for large commercial sites, such as industrial/commercial complexes, where an individual may only be exposed in a small section of land (such as a small shop). The same situation applies for large site redevelopments, which result in subdivision into residential lots. In this case the statistical mean based on site-wide data may not be representative, and concentrations representative of localised areas relevant to potential exposure should be considered.
- When comparing groundwater monitoring results to HSLs, consideration should be given to the maximum reported concentration, or a concentration that represents the likely exposure for a given receptor. Limited number of groundwater wells makes statistical analysis unsuitable. Consideration of groundwater trends is also important, i.e. is the concentration increasing or decreasing.
- Soil vapour HSLs should be compared to measurements of vapour sources and soil vapour above sources, and hence measurements should be taken as laterally close as possible to the soil or groundwater source. Soil vapour measurements require consideration of where the sample is taken, the current state of the site and the future state of the site. Shallow soil-gas measurements (less than 1 m) in open space areas may be subject to influence of their surroundings such as weather conditions and moisture. Nested soil vapour samples of varying depths can be useful to assess the source and show the change of soil vapour concentration with depth, potentially highlighting where degradation of vapours is occurring.

- Groundwater and soil vapour HSLs have been derived assuming a non-depleting source (i.e. infinite source). Soil HSLs for vapour intrusion have been based on a finite source model with an initial contamination layer thickness of 2 m.

Shallow groundwater

- Groundwater HSLs have not been derived for shallow groundwater (i.e. shallower than 2m) where direct contact with contaminated water is possible through shallow excavations. For vapour intrusion into a building, sub-slab soil vapour measurements may be used as a preferred option.

Mixtures

- The HSLs for TPH fractions are based on a composition typical of petrol for lighter chain hydrocarbons and diesel fuel for heavier chain hydrocarbons. Where contamination consists of atypical mixtures a higher tier risk assessment may need to be undertaken in accordance with the requirements of the NEPM.
- If carcinogenic PAHs including benzo(a)pyrene are identified at a site, these concentrations should be compared with the appropriate health investigation levels (HIL) presented in the NEPM.
- Fuel additives such as MTBE have not been included in the derivation of HSLs. If such chemicals are identified in the site contamination assessment, then a site-specific assessment should be carried out.
- HSLs have been derived for indicator chemicals and TPH fractions assuming that the contamination comprises petroleum hydrocarbons and is derived from petrol and diesel fuels. If non-petroleum contaminants are identified at the site, then the potential for cumulative effects of chemicals should be considered. The effect of ethanol concentration greater than 10% in the fuels on the HSLs is currently unclear.

Application depths

- The applicable depth range for the sample should be chosen based on the sample location, whether it is soil or groundwater. For soil vapour, if the measurement is taken from groundwater headspace (i.e. vapour from within the groundwater well in equilibrium with the groundwater), then the applicable depth should be the groundwater table depth.
- For vapour intrusion into buildings the depth to contamination should be considered relative to the underside of the building slab. Therefore when considering basements, 0 m is the location directly under the basement floor. The location considered should be where the soil touches the underside of the concrete slab, not the footings.
- Soil HSLs for direct contact (Table 4) should be applied where direct contact is deemed likely, such as surface soil (i.e. surface to 1 m). At uncontrolled sites (e.g. low-density residential) where there may be bulk soil movement, such as excavation associated with building works, a swimming pool or cellar, contaminated soil at depth may be relocated to the surface of the site. For such sites, consideration may be given to use of HSLs for direct contact and HSLs for vapour intrusion from 0 to <1m, for deeper soils.

Adjustment to reflect field observations

- Soil HSLs for vapour intrusion (Table 3) incorporate an adjustment factor of 10 to the vapour phase partitioning to reflect the differences observed between theoretical estimates of soil vapour partitioning and field measurements (refer to Friebel & Nadebaum 2011 – Part 1 for further information). This does not apply to soil HSLs for direct contact (Table 4).

Vapour biodegradation

- Vapour biodegradation has not been included as a default assumption in the derivation of HSLs for soil (Table 3), groundwater (Table 2) or soil vapour (Table 1).
- Davis, Patterson & Trefry (2009) (CRC CARE Technical Report no. 12) report that for petroleum hydrocarbons, emission reduction factors may be applied to vapour HSLs due to vapour degradation under specific circumstances. This may involve a reduction factor of 10 or 100 for sites where the slab area is small and the presence of oxygen in soil is indicated. For further details refer to Section 7.4 of the technical development document (Friebel & Nadebaum 2011 – Part 1). Guidance on the field assessment of vapours is presented in Davis, Wright & Patterson (2009) (CRC CARE Technical Report no. 13). This document outlines the advantages and disadvantages of a range of vapour sampling and analysis approaches. It is recommended that these reports be referred to before applying adjustments for vapour biodegradation.

Other considerations

- Even though vapour risks may be acceptable when the HSL exceeds the soil saturation limit, consideration should be given to the potential for other effects such as the contamination forming a source of unacceptable groundwater pollution. Local regulatory agencies can have specific requirements for the management and clean-up of separate phase or mobile hydrocarbons.
- Accepted techniques for sampling and analysis of chemicals (BTEX, TPH and naphthalene) must be applied when determining the concentrations that are to be compared with the soil, groundwater and soil vapour HSLs.
- When HSLs are exceeded it does not automatically indicate an unacceptable risk, and therefore should not automatically be viewed as clean-up criteria, but rather a trigger for further investigation or evaluation of management options.
- Where possible, a multiple lines of evidence approach should be considered when assessing the vapour intrusion pathway.
- If the assumptions underlying the derivation of HSLs are not valid for a specific site then a site-specific, higher tier assessment of vapour intrusion may need to be undertaken. Such a higher tier assessment may include different assumptions and/or different parameter values as long as these are adequately justified based on site-specific data (refer to the application document, Friebel & Nadebaum 2011 – Part 2).

TABLE 1
SOIL VAPOUR HEALTH SCREENING LEVELS (mg/m³)^(a,b,c,e)

CHEMICAL ^(f)	HSL-A (Low Density Residential) and HSL-B (High Density Residential) ^(d)				
	0 to <1m	1m to <2m	2m to <4m	4m to <8m	8m+
SAND^(g)					
Toluene	1,300.	3,800.	7,300.	15,000.	29,000.
Ethylbenzene	330.	1,100.	2,200.	4,300.	8,700.
Xylenes	220.	750.	1,500.	3,000.	6,100.
Naphthalene	0.78	3.0	6.1	12.	25.
Benzene	0.99	2.9	5.7	11.	22.
C6-C10	180.	640.	1,300.	2,600.	5,300.
>C10-C16	130.	560.	1,200.	2,400.	4,800.
SILT^(g)					
Toluene	1,400.	14,000.	32,000.	69,000.	140,000.
Ethylbenzene	380.	4,200.	9,700.	21,000.	43,000.
Xylenes	260.	2,900.	6,800.	15,000.	30,000.
Naphthalene	0.90	12.	27.	59.	120.
Benzene	1.1	11.	25.	53.	110.
C6-C10	210.	2,600.	6,000.	13,000.	26,000.
>C10-C16	160.	2,300.	5,400.	NL	NL
CLAY^(g)					
Toluene	1,600.	23,000.	53,000.	110,000.	NL
Ethylbenzene	420.	6,800.	16,000.	35,000.	NL
Xylenes	280.	4,800.	11,000.	24,000.	50,000.
Naphthalene	1.0	18.	44.	94.	200.
Benzene	1.2	17.	41.	88.	180.
C6-C10	230.	4,200.	9,900.	21,000.	44,000.
>C10-C16	180.	3,800.	NL	NL	NL

Notes:

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 to occur.

Refer to Section 7.4 of Friebel & Nadebaum 2011 (CRC CARE Technical Report no. 10: Part 1) or Davis, Patterson & Trefry 2009 (CRC CARE Technical Report no. 12) for further information.

NL - denotes no level presented as HSL exceeds concentration of pure gas

(a) Detailed assumptions used in the derivation of the HSLs and information on how to apply the HSLs are presented in:

- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 1: Technical development document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.
- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 2: Application document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.

(b) The key limitations in the development of the HSLs should be referred to prior to application. These are presented in the text of the summary document and the HSL application checklist in Appendix A of the Application Document (Friebel & Nadebaum 2011 - Part 2).

(c) Soil vapour HSLs should be compared to 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 soil-gas measurements in open space areas (less than 1 m below ground surface) may be subject to strong influences of weather conditions and moisture.

(d) HSLs for vapour intrusion into high-density residential buildings are based on occupation of the ground floor. If residents occupy ground floor apartments, HSL-B should be used. If the ground floor consists of commercial properties or if the building contains a communal basement car park, commercial use (HSL-D) may be applied instead.

(e) The maximum possible soil vapour concentration has been calculated based on the vapour pressures of the pure chemicals. Where soil vapour HSLs exceed these values 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. These are denoted as not limiting, 'NL'.

(f) Chemicals in the TPH >C16 fraction have physical properties which make this TPH fraction non-volatile, and therefore are not of concern for vapour intrusion.

(g) For soil assessment (texture classification) undertaken in accord with AS 1726 the classifications of sand, silt and clay may be applied as coarse, fine with liquid limit less than 50%, and fine with liquid limit greater than 50% respectively, as the underlying properties used to develop the HSLs may reasonably be selected to be similar. Where there is uncertainty, laboratory analysis should be carried out.

TABLE 1 (cont)

SOIL VAPOUR HEALTH SCREENING LEVELS (mg/m³)^(a,b,c,d)

CHEMICAL ^(e)	HSL-C (Recreational / Open Space)					HSL-D (Commercial / Industrial)				
	0 to <1m	1m to <2m	2m to <4m	4m to <8m	8m+	0 to <1m	1m to <2m	2m to <4m	4m to <8m	8m+
SAND^(f)										
Toluene	NL	NL	NL	NL	NL	4,800.	16,000.	39,000.	84,000.	NL
Ethylbenzene	NL	NL	NL	NL	NL	1,300.	4,600.	11,000.	25,000.	53,000.
Xylenes	NL	NL	NL	NL	NL	840.	3,200.	8,000.	18,000.	37,000.
Naphthalene	410.	NL	NL	NL	NL	2.9	13.	33.	73.	150.
Benzene	360.	2,400.	4,700.	9,500.	19,000.	3.7	12.	30.	65.	130.
C6-C10	86,000.	NL	NL	NL	NL	680.	2,800.	7,000.	15,000.	32,000.
>C10-C16	NL	NL	NL	NL	NL	500.	2,400.	NL	NL	NL
SILT^(f)										
Toluene	NL	NL	NL	NL	NL	5,700.	63,000.	NL	NL	NL
Ethylbenzene	NL	NL	NL	NL	NL	1,500.	19,000.	54,000.	NL	NL
Xylenes	NL	NL	NL	NL	NL	1,000.	13,000.	38,000.	NL	NL
Naphthalene	NL	NL	NL	NL	NL	3.7	52.	150.	350.	750.
Benzene	1,800.	12,000.	24,000.	48,000.	97,000.	4.4	48.	140.	320.	670.
C6-C10	NL	NL	NL	NL	NL	850.	11,000.	33,000.	77,000.	160,000.
>C10-C16	NL	NL	NL	NL	NL	670.	NL	NL	NL	NL
CLAY^(f)										
Toluene	NL	NL	NL	NL	NL	6,500.	100,000.	NL	NL	NL
Ethylbenzene	NL	NL	NL	NL	NL	1,800.	31,000.	NL	NL	NL
Xylenes	NL	NL	NL	NL	NL	1,200.	21,000.	NL	NL	NL
Naphthalene	NL	NL	NL	NL	NL	4.3	83.	240.	560.	1,200.
Benzene	3,000.	20,000.	40,000.	81,000.	160,000.	5.0	78.	230.	530.	1,100.
C6-C10	NL	NL	NL	NL	NL	1,000.	19,000.	55,000.	130,000.	270,000.
>C10-C16	NL	NL	NL	NL	NL	800.	NL	NL	NL	NL

Notes:

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 to occur.

Refer to Section 7.4 of Friebel & Nadebaum 2011 (CRC CARE Technical Report no. 10: Part 1) or Davis, Patterson & Trefry 2009 (CRC CARE Technical Report no. 12) for further information.

NL - denotes no level presented as HSL exceeds concentration of pure gas

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(b) The key limitations in the development of the HSLs should be referred to prior to application. These are presented in the text of the summary document and the HSL application checklist in Appendix A of the Application Document (Friebel & Nadebaum 2011 - Part 2).

(c) Soil vapour HSLs should be compared to 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 soil-gas measurements in open space areas (less than 1 m below ground surface) may be subject to strong influences of weather conditions and moisture.

(d) The maximum possible soil vapour concentration has been calculated based on the vapour pressures of the pure chemicals. Where soil vapour HSLs exceed these values 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. These are denoted as not limiting, 'NL'.

(e) Chemicals in the TPH >C16 fraction have physical properties which make this TPH fraction non-volatile, and therefore are not of concern for vapour intrusion.

(f) For soil assessment (texture classification) undertaken in accord with AS 1726 the classifications of sand, silt and clay may be applied as coarse, fine with liquid limit less than 50%, and fine with liquid limit greater than 50% respectively, as the underlying properties used to develop the HSLs may reasonably be selected to be similar. Where there is uncertainty, laboratory analysis should be carried out.

TABLE 2
GROUNDWATER HEALTH SCREENING LEVELS FOR VAPOUR INTRUSION (mg/L) ^(a,b)

CHEMICAL ^(e)	HSL-A (Low Density Residential) and HSL-B (High Density Residential) ^(d)			Solubility Limit ^(c)
	2 to <4m	4m to <8m	8m+	
SAND ^(f)				
Toluene	NL	NL	NL	61.
Ethylbenzene	NL	NL	NL	3.9
Xylenes	NL	NL	NL	21.
Naphthalene	NL	NL	NL	0.17
Benzene	0.78	0.8	0.85	59.
C6-C10	0.98	1.0	1.0	9.0
>C10-C16	1.1	1.1	1.2	3.0
SILT ^(f)				
Toluene	NL	NL	NL	61.
Ethylbenzene	NL	NL	NL	3.9
Xylenes	NL	NL	NL	21.
Naphthalene	NL	NL	NL	0.17
Benzene	4.3	4.5	4.7	59.
C6-C10	5.7	5.8	5.9	9.0
>C10-C16	NL	NL	NL	3.0
CLAY ^(f)				
Toluene	NL	NL	NL	61.
Ethylbenzene	NL	NL	NL	3.9
Xylenes	NL	NL	NL	21.
Naphthalene	NL	NL	NL	0.17
Benzene	4.6	4.8	5.2	59.
C6-C10	NL	NL	NL	9.0
>C10-C16	NL	NL	NL	3.0

Notes:

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 to occur.

Refer to Section 7.4 of Friebel & Nadebaum 2011 (CRC CARE Technical Report no. 10: Part 1) or Davis, Patterson & Trefry 2009 (CRC CARE Technical Report no. 12) for further information.

(a) Detailed assumptions used in the derivation of the HSLs and information on how to apply the HSLs are presented in:

- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 1: Technical development document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.
- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 2: Application document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.

(b) The key limitations in the development of the HSLs should be referred to prior to application. These are presented in the text of the summary document and the HSL application checklist in Appendix A of the Application Document (Friebel & Nadebaum 2011 - Part 2).

(c) 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 which 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. These are denoted as not limiting, 'NL'.

(d) HSLs for vapour intrusion into high-density residential buildings are based on occupation of the ground floor. If residents occupy ground floor apartments, HSL-B should be used. If the ground floor consists of commercial properties or if the building contains a communal basement car park, commercial use (HSL-D) may be applied instead.

(e) Chemicals in the TPH >C16 fraction have physical properties which make this TPH fraction non-volatile, and therefore are not of concern for vapour intrusion.

(f) For soil assessment (texture classification) undertaken in accord with AS 1726 the classifications of sand, silt and clay may be applied as coarse, fine with liquid limit less than 50%, and fine with liquid limit greater than 50% respectively, as the underlying properties used to develop the HSLs may reasonably be selected to be similar. Where there is uncertainty, laboratory analysis should be carried out.

TABLE 2 (cont)

GROUNDWATER HEALTH SCREENING LEVELS FOR VAPOUR INTRUSION (mg/L)^(a,b)

CHEMICAL ^(d)	HSL-C (Recreational / Open Space)			HSL-D (Commercial / Industrial)			Solubility Limit ^(c)
	2 to <4m	4m to <8m	8m+	2 to <4m	4m to <8m	8m+	
<i>SAND</i> ^(e)							
Toluene	NL	NL	NL	NL	NL	NL	61.
Ethylbenzene	NL	NL	NL	NL	NL	NL	3.9
Xylenes	NL	NL	NL	NL	NL	NL	21.
Naphthalene	NL	NL	NL	NL	NL	NL	0.17
Benzene	NL	NL	NL	4.9	5.1	5.4	59.
C6-C10	NL	NL	NL	6.2	6.3	6.5	9.0
>C10-C16	NL	NL	NL	NL	NL	NL	3.0
<i>SILT</i> ^(e)							
Toluene	NL	NL	NL	NL	NL	NL	61.
Ethylbenzene	NL	NL	NL	NL	NL	NL	3.9
Xylenes	NL	NL	NL	NL	NL	NL	21.
Naphthalene	NL	NL	NL	NL	NL	NL	0.17
Benzene	NL	NL	NL	28.	28.	30.	59.
C6-C10	NL	NL	NL	NL	NL	NL	9.0
>C10-C16	NL	NL	NL	NL	NL	NL	3.0
<i>CLAY</i> ^(e)							
Toluene	NL	NL	NL	NL	NL	NL	61.
Ethylbenzene	NL	NL	NL	NL	NL	NL	3.9
Xylenes	NL	NL	NL	NL	NL	NL	21.
Naphthalene	NL	NL	NL	NL	NL	NL	0.17
Benzene	NL	NL	NL	29.	30.	33.	59.
C6-C10	NL	NL	NL	NL	NL	NL	9.0
>C10-C16	NL	NL	NL	NL	NL	NL	3.0

Notes:

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 to occur.

Refer to Section 7.4 of Friebel & Nadebaum 2011 (CRC CARE Technical Report no. 10: Part 1) or Davis, Patterson & Trefry 2009 (CRC CARE Technical Report no. 12) for further information.

(a) Detailed assumptions used in the derivation of the HSLs and information on how to apply the HSLs are presented in:

- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 1: Technical development document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.
- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 2: Application document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.

(b) The key limitations in the development of the HSLs should be referred to prior to application. These are presented in the text of the summary document and the HSL application checklist in Appendix A of the Application Document (Friebel & Nadebaum 2011 - Part 2).

(c) 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 which 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. These are denoted as not limiting, 'NL'.

(d) Chemicals in the TPH >C16 fraction have physical properties which make this TPH fraction non-volatile, and therefore are not of concern for vapour intrusion.

(e) For soil assessment (texture classification) undertaken in accord with AS 1726 the classifications of sand, silt and clay may be applied as coarse, fine with liquid limit less than 50%, and fine with liquid limit greater than 50% respectively, as the underlying properties used to develop the HSLs may reasonably be selected to be similar. Where there is uncertainty, laboratory analysis should be carried out.

TABLE 3
SOIL HEALTH SCREENING LEVELS FOR VAPOUR INTRUSION (mg/kg)^(a,b,c)

CHEMICAL ^(f)	HSL-A (Low Density Residential) and HSL-B (High Density Residential) ^(g)				Saturation Conc. (C _{sat}) ^(d)
	0m to <1m	1m to <2m	2m to <4m	4m+	
SAND ^(h)					
Toluene	160.	220.	310.	540.	560.
Ethylbenzene	57.	NL	NL	NL	64.
Xylenes	40.	59.	94.	170.	300.
Naphthalene	3.	9.	NL	NL	9.
Benzene	0.5	0.5	0.5	0.5	360.
C6-C10	44. ^(g)	70. ^(g)	110. ^(g)	200. ^(g)	950.
>C10-C16	110.	240.	440.	NL	560.
SILT ^(h)					
Toluene	390.	NL	NL	NL	640.
Ethylbenzene	NL	NL	NL	NL	69.
Xylenes	93.	210.	NL	NL	330.
Naphthalene	4.	NL	NL	NL	10.
Benzene	0.6	0.7	1.	2.	440.
C6-C10	41.	64.	100.	190.	910.
>C10-C16	230.	NL	NL	NL	570.
CLAY ^(h)					
Toluene	480.	NL	NL	NL	630.
Ethylbenzene	NL	NL	NL	NL	68.
Xylenes	110.	310.	NL	NL	330.
Naphthalene	5.	NL	NL	NL	10.
Benzene	0.7	1.	2.	3.	430.
C6-C10	50.	88.	150.	290.	850.
>C10-C16	280.	NL	NL	NL	560.

Notes:

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 to occur.

Refer to Section 7.4 of Friebel & Nadebaum 2011 (CRC CARE Technical Report no. 10: Part 1) or Davis, Patterson & Trefry 2009 (CRC CARE Technical Report no. 12) for further information.

(a) Detailed assumptions used in the derivation of the HSLs and information on how to apply the HSLs are presented in:

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(b) The key limitations in the development of the HSLs should be referred to prior to application. These are presented in the text of the summary document and the HSL application checklist in Appendix A of the Application Document (Friebel & Nadebaum 2011 - Part 2).

(c) Soil HSLs for vapour intrusion incorporate an adjustment factor of 10 applied to the vapour phase partition to reflect the differences observed between theoretical estimates of soil vapour partitioning and field measurements. Refer to Section 7.5 of the Technical Development Document (Friebel & Nadebaum 2011 - Part 1) for further information.

(d) 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 which 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. These are denoted as not limiting, 'NL'.

(e) HSLs for vapour intrusion into high-density residential buildings are based on occupation of the ground floor. If residents occupy ground floor apartments, HSL-B should be used. If the ground floor consists of commercial properties or if the building contains a communal basement car park, commercial use (HSL-D) may be applied instead.

(f) Chemicals in the TPH >C16 fraction have physical properties which make this TPH fraction non-volatile, and therefore are not of concern for vapour intrusion.

(g) The HSLs for TPH C6-C10 in sandy soil are based on a 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 Friebel & Nadebaum 2011 - Part 1, Section 8.2 and Appendix J.

(h) For soil assessment (texture classification) undertaken in accord with AS 1726 the classifications of sand, silt and clay may be applied as coarse, fine with liquid limit less than 50%, and fine with liquid limit greater than 50% respectively, as the underlying properties used to develop the HSLs may reasonably be selected to be similar. Where there is uncertainty, laboratory analysis should be carried out.

TABLE 3 (cont)

SOIL HEALTH SCREENING LEVELS FOR VAPOUR INTRUSION (mg/kg) ^(a,b,c)

CHEMICAL ^(e)	HSL-C (Recreational / Open Space)				HSL-D (Commercial / Industrial)				Saturation Conc. (C _{sat}) ^(d)
	0m to <1m	1m to <2m	2m to <4m	4m+	0m to <1m	1m to <2m	2m to <4m	4m+	
SAND ^(g)									
Toluene	NL	NL	NL	NL	NL	NL	NL	NL	560.
Ethylbenzene	NL	NL	NL	NL	NL	NL	NL	NL	64.
Xylenes	NL	NL	NL	NL	230.	NL	NL	NL	300.
Naphthalene	NL	NL	NL	NL	NL	NL	NL	NL	9.
Benzene	NL	NL	NL	NL	3.	3.	3.	3.	360.
C6-C10	NL	NL	NL	NL	260. ^(f)	370. ^(f)	630. ^(f)	NL ^(f)	950.
>C10-C16	NL	NL	NL	NL	NL	NL	NL	NL	560.
SILT ^(g)									
Toluene	NL	NL	NL	NL	NL	NL	NL	NL	640.
Ethylbenzene	NL	NL	NL	NL	NL	NL	NL	NL	69.
Xylenes	NL	NL	NL	NL	NL	NL	NL	NL	330.
Naphthalene	NL	NL	NL	NL	NL	NL	NL	NL	10.
Benzene	NL	NL	NL	NL	4.	4.	6.	10.	440.
C6-C10	NL	NL	NL	NL	250.	360.	590.	NL	910.
>C10-C16	NL	NL	NL	NL	NL	NL	NL	NL	570.
CLAY ^(g)									
Toluene	NL	NL	NL	NL	NL	NL	NL	NL	630.
Ethylbenzene	NL	NL	NL	NL	NL	NL	NL	NL	68.
Xylenes	NL	NL	NL	NL	NL	NL	NL	NL	330.
Naphthalene	NL	NL	NL	NL	NL	NL	NL	NL	10.
Benzene	NL	NL	NL	NL	4.	6.	9.	18.	430.
C6-C10	NL	NL	NL	NL	310.	480.	NL	NL	850.
>C10-C16	NL	NL	NL	NL	NL	NL	NL	NL	560.

Notes:

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 to occur.

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(a) Detailed assumptions used in the derivation of the HSLs and information on how to apply the HSLs are presented in:

- Friebe, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 1: Technical development document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.
- Friebe, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 2: Application document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.

(b) The key limitations in the development of the HSLs should be referred to prior to application. These are presented in the text of the summary document and the HSL application checklist in Appendix A of the Application Document (Friebe & Nadebaum 2011 - Part 2).

(c) Soil HSLs for vapour intrusion incorporate an adjustment factor of 10 applied to the vapour phase partition to reflect the differences observed between theoretical estimates of soil vapour partitioning and field measurements. Refer to Section 7.5 of the Technical Development Document (Friebe & Nadebaum 2011 - Part 1) for further information.

(d) 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 which 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. These are denoted as not limiting, 'NL'.

(e) Chemicals in the TPH >C16 fraction have physical properties which make this TPH fraction non-volatile, and therefore are not of concern for vapour intrusion.

(f) The HSLs for TPH C6-C10 in sandy soil are based on a 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 Friebe & Nadebaum 2011 - Part 1, Section 8.2 and Appendix J.

(g) For soil assessment (texture classification) undertaken in accord with AS 1726 the classifications of sand, silt and clay may be applied as coarse, fine with liquid limit less than 50%, and fine with liquid limit greater than 50% respectively, as the underlying properties used to develop the HSLs may reasonably be selected to be similar. Where there is uncertainty, laboratory analysis should be carried out.

TABLE 4

SOIL HEALTH SCREENING LEVELS FOR DIRECT CONTACT (mg/kg)^(a,b)

Chemical	HSL-A Residential (Low Density)	HSL-B Residential (High Density)	HSL-C Recreational / Open Space	HSL-D Commercial / Industrial
Toluene	14,000.	21,000.	18,000.	99,000.
Ethylbenzene	4,500.	5,900.	5,300.	27,000.
Xylenes	12,000.	17,000.	15,000.	81,000.
Naphthalene	1,400.	2,200.	1,900.	11,000.
Benzene	100.	140.	120.	430.
C6-C10	4,400.	5,600.	5,100.	26,000.
>C10-C16	3,300.	4,200.	3,800.	20,000.
>C16-C34	4,500.	5,800.	5,300.	27,000.
>C34-C40	6,300.	8,100.	7,400.	38,000.

Notes:

(a) Detailed assumptions used in the derivation of the HSLs and information on how to apply the HSLs are presented in:

- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 1: Technical development document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.
- Friebel, E & Nadebaum, P 2011, *Health screening levels for petroleum hydrocarbons in soil and groundwater. Part 2: Application document*, CRC CARE Technical Report no. 10, CRC for Contamination Assessment and Remediation of the Environment, Adelaide, Australia.

(b) The key limitations in the development of the HSLs should be referred to prior to application. These are presented in the text of the summary document and the HSL application checklist in Appendix A of the Application Document (Friebel & Nadebaum 2011 - Part 2).



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