Ministry for the Environment
Manatū Mō Te Taiao

Guidelines for Assessing and Managing Petroleum Hydrocarbon Contaminated Sites in New Zealand (Revised 2011)

MODULE 4

Tier 1 soil acceptance criteria

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This module outlines the development of Tier 1 soil acceptance criteria for a range of land uses and environmental settings, which can provide the basis for the assessment and management of petroleum hydrocarbon contaminated sites. The application of the Tier 1 acceptance criteria is outlined in Module 1 and is discussed in greater detail in Section 4.8. The criteria are only applicable to releases of petroleum hydrocarbon products (e.g. gasoline, diesel, kerosene), not pure solvents.

This module has been prepared in the context of two objectives as follow:

- establishing the detailed procedure for developing soil acceptance criteria
- developing generic (Tier 1) soil acceptance criteria.

The detailed procedures presented in this module may be used as the basis for the development of site-specific soil acceptance criteria (Tier 2); substituting site-specific information for the generic exposure assumptions used in the derivation of the Tier 1 soil acceptance criteria.

4.1 Basis for derivation of Tier 1 acceptance criteria

The basis for the derivation of Tier 1 soil acceptance criteria is presented including consideration of land use, contaminants and environmental settings.

The Tier 1 soil acceptance criteria have been developed on a risk basis. Appendix 4A outlines a general approach to the assessment of risk associated with a contaminated site. The conventional risk assessment process is operated in reverse in order to derive risk-based soil acceptance criteria. The general steps associated with the derivation of risk-based soil acceptance criteria are outlined as follows:

- policy decisions regarding tolerable levels of risk for derivation of Tier 1 soil acceptance criteria
- identification of contaminants of concern, receptors and exposure pathways to be considered
- toxicity assessment (required to relate policy decisions regarding tolerable levels of risk to tolerable levels of exposure)
- exposure assessment (relates tolerable level of exposure to tolerable contaminant concentrations in relevant exposure media)
- consideration of factors other than health risks impacting on the acceptability of contamination (e.g. ecological impact, aesthetic impact)
- nomination of risk-based Tier 1 soil acceptance criteria.

The use of risk assessment in the development of acceptance criteria facilitates a technically defensible approach that may be readily modified to account for site-specific considerations. Further the development of soil acceptance criteria using risk assessment principles and techniques is an integral part of the risk-based approach to the assessment and management of contaminated land.

In the derivation of soil acceptance criteria, the primary consideration has been protection of human health. Consideration has also been given to the protection of ecological receptors and aesthetic quality; these have not been determinants of the Tier 1 soil acceptance. While it is clear that human health must be fully protected for all site uses, there is debate regarding the level of protection that should be afforded to on-site ecological receptors and aesthetic considerations in an industrial or commercial context.

At the moment there are no equivalent Tier 1 ecological acceptance criteria. Instead the ecological concerns are addressed by first using a checklist to identify those few sites where valued ecological receptors may be impacted. At those sites where an ecological receptor may be impacted, a site-specific ecological risk assessment may be conducted as part of a Tier 2 or Tier 3 assessment. A similar approach has been adopted for aesthetic impacts where guidance is provided to assist in site-specific assessment.

Tier 1 soil acceptance criteria have been developed for a range of land uses. Considerations in assessing the suitability of land for various uses is outlined as follows:

Agricultural.	Human health, protection of produce quality, protection of ecological receptors, and aesthetic considerations.
Residential.	Human health, protection of produce quality, protection of ecological receptors (limited), and aesthetic considerations.
Commercial/Industrial Use.	Human health, aesthetic considerations (limited).

In addition to site users directly associated with the above site uses, consideration has been given to other groups that may be exposed to soil contamination, such as maintenance workers.

Due to the dependence of the volatilisation-inhalation exposure pathway (which may be of importance for some constituents of gasoline, refer Section 4.3) on the site characteristics, Tier 1 acceptance criteria have been developed for a range of environmental settings. The environmental settings include consideration of:

- soil type (and properties)
- depth to contamination
- depth to groundwater
- groundwater quality and yield
- proximity to surface water
- land use (including surrounding land use).

Figure 4.1 illustrates the range of scenarios for which Tier 1 soil acceptance criteria have been developed.

The volatilisation of contaminants from soil depends heavily on the soil and the nature of the receiving environment (e.g. indoor air, through concrete foundations). Given the variability in soil types between sites, Tier 1 acceptance criteria have been developed for a range of soil types in order to avoid the need to uniformly adopt a single conservative set of soil properties.

Comment on issues associated with the soil acceptance criteria and liquid-phase hydrocarbons is given in Section 4.1.1 below). To assist in assessing the possible impact of soil contamination on groundwater quality, Tier 1 soil acceptance criteria based on the protection of groundwater have been developed. It is intended that such criteria may be used as a screening tool to assist in determining whether residual soil contamination is likely to adversely impact groundwater quality. Where the contaminant release occurred a significant time prior to the assessment, direct measurement of groundwater quality may provide the most reliable indicator of impact. The Tier 1 soil acceptance criteria for the protection of groundwater quality may be of use in assessing possible future impact on groundwater quality where:

- a release has occurred recently (and is unlikely to have reached groundwater yet), or
- some residual soil contamination remains following remediation of the main source of groundwater contamination (e.g. residual soil contamination at the base of a tank pit excavation).

The derivation of Tier 1 soil acceptance criteria presented in this module is specific to on-site receptors, and does not consider the protection of the off-site environment. Site-specific consideration must be given to the impact of soil contamination on groundwater and surface water quality. Tier 1 soil acceptance criteria for the protection of groundwater quality are presented to assist in this evaluation. In most cases acceptance criteria protective of on-site receptors will also be protective of the off-site environment.

4.1.1 Acceptance criteria and liquid-phase hydrocarbons

The following section aims to provide guidance on the potential human health and environmental risks associated with the presence of liquid phase hydrocarbons and the relationship between liquid phase hydrocarbons and the Tier 1 acceptance criteria. Comment is also provided on issues associated with the investigation and management of liquid phase hydrocarbon contamination. Background information on the occurrence and migration of liquid phase hydrocarbon at petroleum hydrocarbon contaminated sites is detailed in Sections 2.4.1 and 2.5.3.

Liquid phase hydrocarbon and the Tier 1 acceptance criteria

The background to the phase partitioning relationships between adsorbed, dissolved, vapour and liquid phase hydrocarbons is given in Appendix 4M. Where the concentration of hydrocarbons in the soil is low, hydrocarbon will typically be present in an adsorbed, vapour and dissolved phase. However, as the concentration increases liquid phase hydrocarbons will tend to form. Initially liquid phase hydrocarbon will tend to be immobile and trapped within the soil matrix. As the mass/volume increases then the liquid phase hydrocarbons will become more mobile and begin to migrate. As the contamination begins to accumulate on the capillary fringe (Section 2.5.3) a more distinct floating layer will form within the soil matrix.

Where a floating layer of liquid phase hydrocarbon is present on site, the soil contaminant concentrations associated with the liquid phase hydrocarbon are likely to be highly elevated and the assumptions on which the Tier 1 soil acceptance criteria, as presented in Module 4, were developed/modelled may not hold. In particular, for the inhalation pathway, the volatilisation models used to develop the Tier 1 acceptance criteria assume a linear partitioning relationship. However, where liquid phase hydrocarbon is present this relationship is invalid. The volatilisation modelling will tend to over estimate the rate of volatilisation where residual liquid phase hydrocarbon is present.

The impact of liquid phase hydrocarbons on the volatilisation modelling should be considered in greater detail as part of a Tier 2 assessment and/or through further investigation, in particular use of soil gas survey techniques. It should be borne in mind that as product weathering occurs, the soil gas survey results will change over time as the product composition changes. It should be stressed that depending on the composition of the product, the soil type, depth and the environmental setting, liquid phase hydrocarbon may not pose a human health or environmental risk.

The groundwater acceptance criteria presented in Module 5, which relate to dissolved phase contamination, are principally controlled by the solubility limits of either the pure compound in water or the compound in water when present as part of a typical gasoline mixture. As a consequence, the level of dissolved phase hydrocarbon groundwater contamination can only reach a theoretical maximum level before liquid phase hydrocarbon will begin to form. Where the calculated human health acceptance criteria exceed the solubility limit (as defined by the letter “S” in the tables) then the dissolved phase contamination is deemed not to pose a risk, as it would not be possible to have dissolved phase hydrocarbon contamination present at levels greater than the solubility limit.

Human health and environmental risk associated with liquid phase hydrocarbon

Liquid phase hydrocarbon can present a risk to human health and the environment through a combination of exposure pathways, as given below:

- Inhalation of vapour or asphyxiation
- Dermal contact with liquid phase hydrocarbon – such as maintenance workers
- Leaching of contaminants from the liquid phase into the underlying groundwater system
- Vapour explosion risk
- Migration of liquid phase hydrocarbon into a surface water environment
- Odour nuisance
- Building material durability/chemical attack

As a consequence, where liquid phase hydrocarbon is proven to be present on-site, it will be necessary to characterise the nature and extent of the product to establish whether a human health and/or environmental risk exists.

For example, where fresh petrol is present on a site as a floating layer of liquid phase hydrocarbon the potential human health and environmental risk is likely to be high. This is principally because of the presence of high vapour concentrations, high concentrations of BTEX compounds within the product and soil, and a high potential for BTEX compounds to leach into an underlying groundwater system. In addition, petrol can also act as a solvent and attack building materials such as plastic pipes, electrical conduits etc. However, if weathered diesel is present on a site as a floating layer of liquid phase, for example, the potential human health risk is likely to be lower because the potential for vapour generation and leaching of contaminants into an underlying groundwater system are less. Although it should be borne in mind that diesel still has the potential to produce vapour contamination. However, liquid phase diesel will pose a maintenance worker human health risk unless certain precautions are taken.

Depending on the type/nature of liquid phase hydrocarbon present on a site, and the quality of the site investigation data, it may be possible to utilise the Tier 1 soil and groundwater acceptance criteria to identify the risk drivers or in certain circumstances establish the level of human health/environmental risk. However, it may be necessary to utilise a more detailed risk assessment approach, as detailed under Tiers 2 or 3 (Module 6), to address the risks from liquid phase hydrocarbons.

Investigation and management

In terms of investigating a site where liquid phase hydrocarbons are suspected, the following issues should be considered:

- Soil samples should be collected within the area of the liquid phase hydrocarbon (i.e. above and below the groundwater table) to enable comparison against the Tier 1 acceptance criteria.
- Various researchers have provided soil and groundwater contaminant concentrations ("rules of thumb") above which a floating layer of liquid phase hydrocarbons could be present. For example, Cohen and Mercer 1993 quote a soil TPH concentration of 10,000 mg/kg (1% of soil mass) and >1% of effective solubility in groundwater.
- Several rounds of groundwater monitoring are likely to be required to establish the true extent, product thickness in groundwater monitoring wells and absence/presence of liquid phase hydrocarbons in wells.
- Groundwater monitoring wells installed immediately down-gradient of an area of liquid phase hydrocarbon will give an indication as to whether dissolved phase hydrocarbon contamination is being generated by the product.
- Soil gas sampling/monitoring will give an indication as to whether vapour phase contamination is being generated by the liquid phase hydrocarbon.
- Consideration should be given to the propensity for liquid phase hydrocarbons to use service trenches etc. as preferential migration pathways, with liquid phase hydrocarbons having the potential to migrate off-site in an opposite direction to groundwater flow through these conduits. Equally mobile liquid phase hydrocarbon can migrate in opposite directions to groundwater flow in the unsaturated zone.

The choice of site management options where floating layers of liquid phase hydrocarbon is present is principally controlled by the risk posed by the liquid phase hydrocarbon and the technical feasibility to recover/remove/isolate the contamination. Whilst it is generally preferable to recover/remove the liquid phase hydrocarbon, because the product is likely to be the principal source of the site contamination and the key risk driver, it may not be technically feasible/practical to undertake these works because of the composition, thickness and extent of the product and nature of the hydrogeological system.

In assessing possible management options for liquid phase hydrocarbons consideration should be given to the following issues:

- There is not a simple linear relationship/conversion scheme between product thickness measured in the monitoring well and the volume of product in the formation (Lenhard and Parker 1990).
- It is not possible to recover the entire volume of liquid phase hydrocarbon that is estimated to be in the formation; much of the liquid phase hydrocarbon is entrained in the soil structure through capillary forces. As a consequence, under most conditions product pumping will not recover more than 50% of the original product in-place, with 30% recovery being typical (Beckett and Lundegard 1997).
- A floating layer of liquid phase hydrocarbon does not always comprise one continuous layer of product within the formation, particularly within heterogeneous strata.

- Under most conditions, recovery of liquid phase hydrocarbons will reduce the longevity of the human health and environmental risk (by mass reduction), but not the magnitude of the risk. As a consequence, other risk management/reduction options should be evaluated/considered (Beckett and Lundegard 1997).

4.2 Risk characterisation and policy decisions

> The risk characterisation relates exposure, toxicity and risk. In deriving risk-based soil acceptance criteria, policy decisions regarding the level of tolerable risk are combined with information from toxicity assessment to determine a tolerable level of exposure. Key policy decisions regarding the tolerable level of risk adopted for the purposes of deriving Tier 1 soil acceptance criteria are presented.

Chemical contaminants may be divided into two broad groups according to their effects on human health, carcinogens and non-carcinogens. The latter group are associated with effects on one or a number of specific body organs or systems, such as the liver or the nervous system. Policy decisions regarding the tolerable level of risk adopted in deriving Tier 1 soil acceptance criteria also reflect this general division.

4.2.1 Carcinogens (non-threshold)

For carcinogenic chemicals an incremental lifetime risk of cancer, associated with exposure to a given chemical, is defined as follows (USEPA, 1989a):

$$\textbf{Risk} = \textbf{CDI} \times \textbf{SF}$$

where: CDI = Chronic Daily Intake (a measure of exposure)

SF = Slope Factor (sometimes called Cancer Potency Factor)

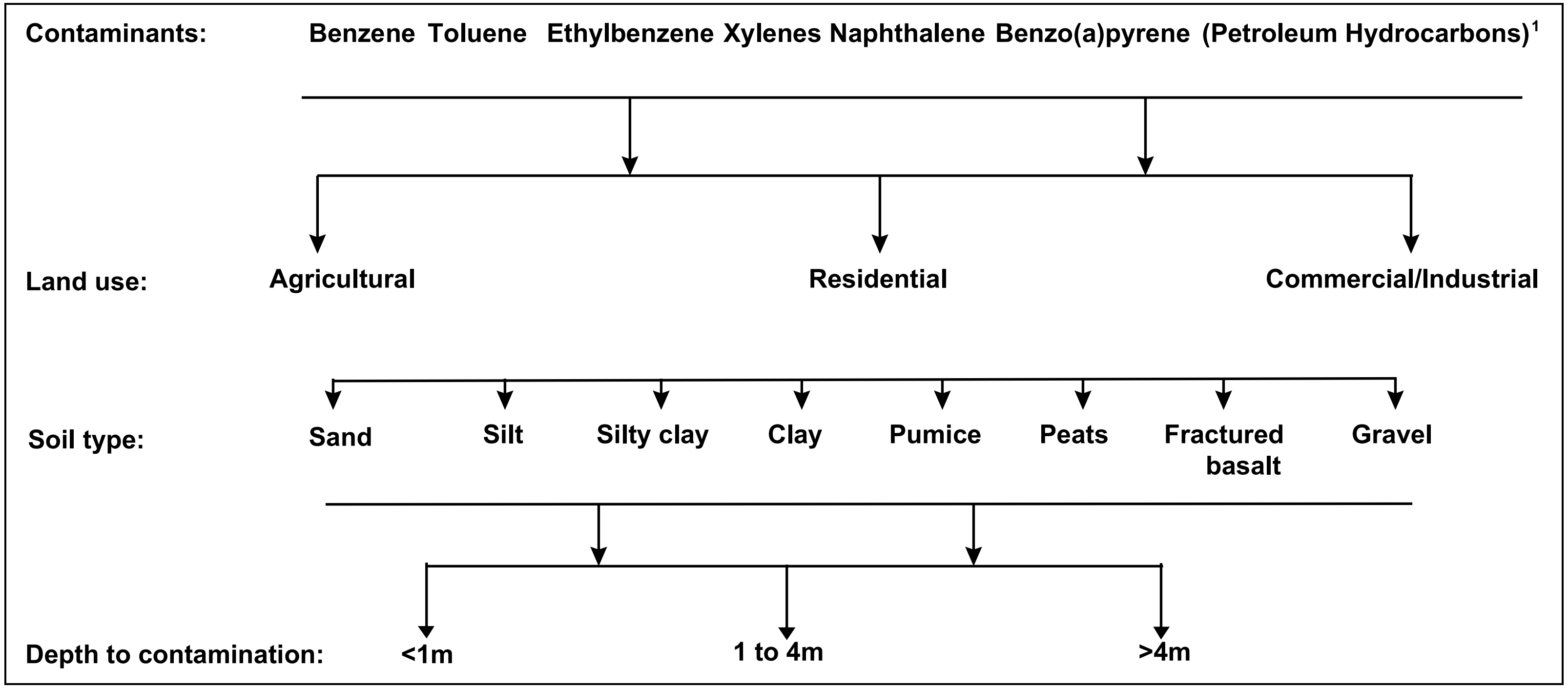
The level of risk that is deemed to be acceptable or tolerable, in a regulatory sense, is an essential judgement in the risk assessment process. While the level of risk deemed to be acceptable is a matter for the community as a whole to decide, the Ministry of Health have adopted an incremental cancer risk level of one in 100,000 per lifetime in derivation of similar guideline values, e.g. *New Zealand Drinking Water Standards* (MoH, 1995), *Health and Environmental Guidelines for Selected Timber Treatment Chemicals* (MfE/MoH, 1997).

On this basis, a cancer risk level of one in 100,000 per lifetime has been adopted for the derivation of Tier 1 soil acceptance criteria for non-threshold (or genotoxic) carcinogens.

The Tier 1 soil acceptance criteria have been derived based on an incremental lifetime risk of cancer of one in 100,000 for each chemical. In practice exposure to more than one carcinogen may occur simultaneously. Where exposure to more than one contaminant may contribute significantly to the overall risk, it may be necessary to adopt lower criteria such that the overall risk does not exceed one in 100,000.

In the case of gasoline releases, benzene is generally the dominant source of carcinogenic risk (refer Section 4.3) and therefore the contribution from other potentially carcinogenic contaminants may be neglected, as part of the Tier 1 assessment, without significantly underestimating the overall risk.

Figure 4.1 Tier 1 soil acceptance criteria scenarios (not including the soil to groundwater pathway)



Notes:

1. Criteria presented for petroleum hydrocarbons should be regarded as of secondary importance only, compared to criteria developed for specific compounds. Criteria are presented to assist in providing a general indication of the risk.
2. Multiple depths to groundwater considered for soil to groundwater pathway.
3. Branches in diagram illustrate how multiple considerations combine to result in a large number of criteria values for each contaminant.

Similarly, the carcinogenic PAHs are generally considered to be the primary source of cancer risk associated with diesel, waste oil and other heavy-fraction petroleum releases. The combined effect of the carcinogenic PAH compounds may be assessed using the Toxic Equivalence Factor (TEF) approach outlined in Section 4.4.

Note that the model of carcinogenicity underlying the USEPA approach assumes that the dose and consequent risk associated with exposure to carcinogens is cumulative over a lifetime.

4.2.2 Non-carcinogens

For non-carcinogenic species a chronic hazard quotient is defined as follows (USEPA, 1989a):

$$HQ = \frac{CDI}{RfDc}$$

where: HQ = Hazard Quotient

CDI = Chronic Daily Intake

RfDc = Chronic Reference Dose (refer Section 4.4)

Where sensitive population groups may be exposed, a HQ of 1 is appropriate to protect human health hence the Chronic Daily Intake is available directly from the literature, i.e. CDI = RfD.

Where more than one species has the same health effect or where exposure to a species may occur by more than one route, the HQ for each combination is summed to give a hazard index, HI. In the absence of further information, it is common practice to consider exposure to each substance separately[1]. Where it is likely that substances may operate by toxicological mechanism which would be likely to give an additive or synergistic effect, then this should be taken into account in the toxicological assessment.

There is some evidence that toluene, ethylbenzene and xylene may act in a similar manner, particularly in relation to neurological effects, and therefore it may be argued that consideration should be given to additive or synergistic effects. Similarly some of the non-carcinogenic PAHs may be expected to exhibit similar effects. However for the purposes of deriving Tier 1 soil acceptance criteria each of the contaminants has been considered separately, with the exception of the carcinogenic PAHs (as noted in Section 4.4). This approach is consistent with the RBCA guidance and the *Drinking-Water Standards for New Zealand* (NZDWS).

Note that the toxicological model underlying the USEPA assessment approach for non-carcinogenic health effects assumes the effects and dose are not necessarily cumulative over a lifetime. The USEPA RfDs for chronic health effects have developed in the context of exposure durations of months to years.

4.2.3 Combining exposure routes

The exposure associated with each exposure route may be considered, in general, to be additive. Therefore the Tier 1 soil acceptance criteria should be based on the soil concentration corresponding to the target risk level based on the cumulative exposure from all exposure routes. The acceptance criteria corresponding to the target risk level for the combined exposure route are readily determined based on acceptance criteria for each individual exposure route. This is based on the assumption that

[1] The combined effect of individual compounds comprising TPH are, in effect, assumed to be simply additive i.e. representative toxicological data is applied to the sum of the concentration of individual compounds as indicated by TPH measurements.

a contaminant acts by a similar mechanism, despite exposure occurring by different exposure routes. While true for some contaminants, many exceptions are noted.

Tier 1 soil acceptance criteria have been nominated on the basis of the combined exposure from all exposure routes considered (with the exception of the soil to groundwater pathway which is considered separately). Route-specific Tier 1 criteria are presented for use where one or more of the exposure routes/pathways are not relevant at a particular site.

In practice, one exposure route is frequently dominant (resulting in a route-specific acceptance criterion that is much lower than for other exposure routes), and therefore the Tier 1 soil acceptance criteria may be determined by selecting the lowest of the route-specific acceptance criteria. Where more than one exposure route is significant, the impact of the combined exposure has been considered, and a note is included to this effect.

4.3 Scope of Tier 1 criteria derivation

The scope of the Tier 1 soil acceptance criteria derivation is defined in terms of the contaminants of potential concern, the land uses to be considered, the receptors potentially exposed, and the exposure pathways to be considered. This step is analogous to the hazard identification step in the conventional health risk assessment framework.

4.3.1 Contaminants of concern

Identification of the contaminants of concern is one of the first steps in risk assessment. Contaminants of concern are selected on the basis of their relative concentration in petroleum products, hazard (health or environment impact), mobility, and persistency.

4.3.1.1 General

As outlined in Module 2, petroleum products are complex mixtures of a range of hydrocarbons and other compounds. A summary of the composition of each of the petroleum products addressed by these guidelines is presented in Table 4.1.

Due to the complex nature of petroleum products, it is impractical to rigorously assess the concentration of, and risk associated with, each of the specific components. Rather, it is necessary to focus attention on the select group of compounds that are likely to pose the greatest risk to human health and to develop indicators that allow an assessment of the overall level of contamination by hydrocarbon compounds.

A screening level assessment of the relative concern associated with hydrocarbon components of gasoline indicates that the risk to human health is governed by a relatively small number of indicator compounds, as shown in Table 4.1 (refer to Appendix 4A).

Table 4.1 Summary of product composition and contaminants of concern

Product	Composition(1)	Indicator contaminants	Relevant analyses
Gasolines	C4 to C12 BTEX 10 to 20% Other aromatics 39% Aliphatics: 49-62% Lead (historical)	benzene, xylene, alkylbenzenes[1], n-hexane and other light alkanes, naphthalene	TPH, BTEX, lead
Diesel	C9 to C20 Aliphatics: 64% Alkenes: 1 to 2% Aromatics: 35% TEX:0.25 to 0.5%	Alkylbenzenes, higher alkanes, naphthalene and other PAHs	TPH, PAHs
Kerosene	C9 to C16 Alkenes: 80% Aromatics: 5 to 20% (mostly alkylbenzenes)	Alkylbenzenes, naphthalene and other PAHs, heavier alkenes	TPH, PAH, BTEX
Jet fuel, JP4	C4 to C16 BTEX: 5% Aromatics: 20% Paraffins: 80%	Benzene(1), xylene, naphthalene, alkylbenzenes, heavier alkanes	TPH, BTEX, PAH
Heavy fuel oils and lube oils	Greater than C12 3 to 7 ring PAHs: 6 to 20% Paraffins: 20% Aromatics: 34% Substituted benzenes: 2%	PAHs including benzo(a)pyrene, heavier alkanes	TPH, PAH
Bitumen	Residue from distillation	PAHs	PAHs

1 Alkyl benzenes may include toluene, ethyl benzene, xylenes and higher substituted benzenes such as tri and tetra-methyl benzene. The higher substituted alkyl benzenes are not expected to be controlling with respect to human health (i.e. health risk associated with higher substituted alkyl benzenes is expected to be substantially less than for some other compounds in petroleum mixtures). However they are part of a range of compounds may contribute to aesthetic impacts noted when other indicator compounds (e.g. benzene) are no longer present at significant concentrations.

The weathering of petroleum products released to the environment means that the hydrocarbon mixtures measured in environmental samples, frequently differ in composition from fresh petroleum products as considered in Table 4.1 and Appendix 4A. Contaminants of concern are usually selected on the basis of relative concentration in the source product and toxicity. However other compounds may persist, possibly resulting in aesthetic impact, when commonly used indicators (selected on the basis of health risk) have been lost by degradation or other processes. Under certain conditions, methane, carbon dioxide and hydrogen sulphide may be present as a result of microbial degradation of hydrocarbons.

In addition to petroleum hydrocarbon compounds, many fuels, particularly gasolines, contain additive chemicals that are designed to improve specific characteristics of the fuel, for example, anti-knocking agents. While such additives are common in gasoline, they are generally only present at very low concentrations, and screening-level risk assessments usually indicate the risk associated with such compounds is secondary to that of benzene, and other petroleum hydrocarbons (Lindon, 1993). A notable exception to this in the United States is methyl tertiary butyl ether (MTBE) which is found to be far more persistent than benzene in groundwater. To date MTBE has not been used as an additive in New Zealand fuels.

The most common additives historically used in gasoline formulations are tetra methyl lead and tetraethyl lead. Lead additives are no longer used in New Zealand fuels. However, lead may be present in areas of historical contamination. Organic lead additives are expected to degrade to inorganic lead compounds over time in the soil environment. In areas of residual separate phase contamination, some organic lead may be found. However, the concern associated with the lead would generally be secondary to the presence of the free product.

Inorganic lead generally exhibits limited mobility in the soil environment. This is consistent with observations at former service station sites where lead contamination resulting from underground leaks and spills is generally confined to the soils immediately surrounding the source of contamination. Further, the concentrations of lead resulting from petroleum contamination are relatively low at most sites (generally less than the ANZECC Environmental Investigation Threshold of 300 mg/kg), with other contaminants being of greater concern to human health. Possible exceptions to this general rule include areas used for the disposal of leaded sludge and localised areas of lead contamination resulting from the storage of lead acid batteries. These issues reinforce the need to carefully review site history information and likely waste disposal practices. Lead associated with storage of petroleum products is not expected to be of concern at the majority of service station sites.

On this basis, lead has not been nominated as a contaminant of concern for the purposes of deriving Tier 1 soil acceptance criteria. Where lead is suspected to be of concern on a site-specific basis, the ANZECC Environmental Investigation Threshold may be adopted as a Tier 1 acceptance criterion.

4.3.1.2 Indicator compounds for Tier 1 soil acceptance criteria

The most rigorous scientific approach to assessing concern associated with petroleum contamination would be to assess the impact of each chemical individually. Clearly this is not a practical alternative, neither is it likely to result in cost-effective risk management. Therefore Tier 1 soil acceptance criteria have been developed for:

- a selected number of indicator contaminants that are likely to pose the greatest concern, and
- TPH, as a general indicator of the level of contamination by a broad range of compounds.

The selection of parameters or contaminants for which to develop soil screening criteria must reflect:

- the contaminants of concern with regard to human health, environment and aesthetic quality
- the contaminants and parameters readily and cost-effectively measured in routine site assessment, given the existing level of laboratory infrastructure in New Zealand.

Given the considerations outlined above, Tier 1 soil acceptance criteria have been developed for the following compounds or classes of compounds:

- benzene, toluene, ethyl-benzene and xylene (BTEX)
- polycyclic aromatic hydrocarbons (PAHs).

The USEPA nominate 16 individual PAHs in the Priority Pollutants List and these are normally used as the basis of laboratory analysis for PAHs. In order to streamline the derivation of Tier 1 soil acceptance criteria the following representative PAHs have been selected for criteria development:

- **Benzo(a)pyrene:** representative of the carcinogenic PAHs (including benzo(a)pyrene, benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(ah)anthracene, and indeno (123-cd) pyrene)
- **Naphthalene:** Naphthalene is a volatile, non-carcinogenic PAH present in fuel at significant concentrations
- **Pyrene:** Representative of the less volatile, non-carcinogenic PAHs (including acenaphthene, acenaphthylene, anthracene, benzo(ghi)perylene, dibenzo(ah)anthracene, fluoranthene, fluorene, phenanthrene pyrene)

In the first instance, criteria developed for pyrene may be used as an indication of the acceptable concentration of total PAHs and the criteria developed for benzo(a)pyrene may be used to assess the range of carcinogenic PAHs by use of toxic equivalency factors (TEFs) and comparison with benzo(a)pyrene equivalent concentrations (refer Section 4.4 for further details).

4.3.1.4 Total petroleum hydrocarbons

In a risk-based approach to site assessment, the first step is to identify whether the Tier 1 acceptance criteria for specific indicator compounds are exceeded. At some sites no specific indicator chemical acceptance criteria will be exceeded, yet significant amounts of a hydrocarbon mixture remain. Usually this is noted through the use of total petroleum hydrocarbon (TPH) analysis.

As part of the risk-based approach we also wish to ensure that the cumulative effect of the remaining hydrocarbons do not pose any adverse impacts. To facilitate this, Tier 1 acceptance criteria have been developed for various hydrocarbon fractions based on representative toxicity and fate and transport information from the TPH Criteria Working Group.

The development of health-based criteria for TPH is problematic and has been subject to considerable debate, given that it represents a complex mixture of compounds. Despite this the TPH Criteria Working Group (TPHCWG), which includes the US Air Force, oil companies, railroad companies, state regulators and the USEPA) has concluded that, while secondary to measure of BTEX and PAH concentrations, TPH measurements may be used to provide an indication of risk at petroleum release sites.

The TPHCWG has developed an approach based on assigning representative fate and transport and toxicological parameters to each TPH fraction (defined in terms of carbon chain length). Tier 1 acceptance criteria may then be derived for each of the TPH fractions using the same procedures used for individual indicator compounds.

While this approach involves a number of simplifying assumptions, it is considered to represent a reasonable approximation for the purposes of developing health-based Tier 1 soil acceptance criteria. A similar approach was developed by the Massachusetts Department of Environmental Protection (MDEP) in 1994.

For the purposes of developing health-based criteria for TPH, the following TPH fractions have been used:

- C7 to C9

- C10 to 14
- C15 to C36.

As part of the derivation of guideline values for the heavier TPH fractions (C10 to C14 and C15 to C36), consideration has been given to the use of TPH as a surrogate measure for PAHs in the case of diesel releases (refer Section 4.8.3).

4.3.2 Land uses

Land-use can have a major impact on the significance of soil and groundwater contamination, and therefore Tier 1 soil acceptance criteria have been developed for a range of land uses.

Land-use is a key determinant of extent to which site users may be exposed to soil contamination and the level of protection to be afforded to the on-site ecosystems. Government policy in New Zealand seeks to ensure that sites are remediated or managed so as to render them suitable for the likely future use of the site. Where a site is remediated for a non-sensitive land use (e.g. commercial land use), consideration should be given to the implementation of institutional controls, or the use of Land Information Memoranda (LIMs) to ensure the site is not redeveloped for a more sensitive use without further consideration (refer Module 7 for further details of site management options).

A very wide range of land uses may be considered in the development of acceptance criteria. For the purposes of deriving Tier 1 soil acceptance criteria, three land uses have been considered:

- **Agricultural/Horticultural**

  Agricultural/Horticultural use includes consideration of use of the land for grazing domestic animals for human consumption, cropping and market gardening. For the purposes of the derivation of Tier 1 soil acceptance criteria, agricultural/ horticultural use also requires consideration of the suitability of the land for residential use.

- **Residential**

  Residential use is the base case for derivation of soil acceptance criteria and historically most attention has been focused on the development of criteria for this use. Residential use is considered to be the most sensitive use reasonably expected in developed/urban areas, particularly in former industrial areas.

- **Commercial/Industrial**

  Commercial/industrial use includes a wide range of less sensitive land uses associated with commercial or industrial development. For the purposes of the derivation of Tier 1 soil acceptance criteria the key characteristics of such a use are the presence of a building and exposure of adults during work hours only. Occasional exposure of children for shorter durations (e.g. in the context of shopping development) is expected to be of lesser concern.

Petroleum contaminated sites may be redeveloped for a wide range of uses. However, those listed above are considered to be the most commonly encountered. Generally the value and location of former petroleum hydrocarbon retail sites makes redevelopment for recreational purposes unlikely and the size of most sites means that institutional use, such as education, is unlikely. If other uses are identified on a site-specific basis, then the next most conservative use listed above may be used or use-specific criteria may be developed as part of a Tier 2 assessment.

The commercial/industrial use outlined above does not include consideration of continued use of a site for petroleum handling facilities. Under such circumstances the requirement to manage exposure to petroleum hydrocarbons emanating from contaminated soil in accordance with the risk policy decisions outlined previously (e.g. incremental lifetime risk of cancer of less than one in 100,000) would be inconsistent with the basis on which other exposure to petroleum hydrocarbons is managed at the same site. In this context the suitability of a site for continued use as a petroleum handling facility should be assessed on the basis of the requirements for occupational health and safety. In particular, for the volatilisation pathway, the Workplace Exposure Limits (8-hour time-weighted average) may be used as target air concentrations (accounting for the contribution from other sources on site), rather than the risk-based limits considered for other land uses. Such an evaluation may be undertaken on a site-specific basis. Tier 1 soil acceptance criteria have not been developed for ongoing use as a petroleum handling facility.

Residential use covers a wide range of use types and corresponding exposure scenarios. The residential use scenario considered for Tier 1 soil acceptance criteria development is based on a low density residential use or possibly a rural residential use. Site-specific consideration may allow higher contaminant concentrations in the context of a high density residential use[2].

4.3.3 Receptors

A receptor is defined as an organism, (including humans), plant or physical structure that receives, may receive or has received environmental exposure to a chemical. In the context of the site uses outlined above, the key human receptors assumed for the purposes of developing soil screening criteria, are presented in Table 4.2. In addition to the receptors listed in Table 4.2, consumers exposed via the consumption of produce (i.e. fruit and vegetables) grown at a contaminated site are considered implicitly given, residents at an agricultural/horticultural site are assumed to obtain 100% of their produce requirements from the site.

The receptors presented in Table 4.2 are also of relevance when considering possible aesthetic impacts.

Table 4.2 Human receptors considered in the derivation of soil screening criteria

Site Use	Receptor Group
Agricultural	Child residents Adult residents/workers Maintenance workers
Residential	Child residents Adult residents Maintenance workers
Commercial/industrial (paved or unpaved)	Adult workers Maintenance workers

4.3.4 Exposure pathways

For soil contamination to pose a risk to a receptor, a complete pathway must exist between the source of contamination and the receptor. Where the exposure pathway is incomplete there is no risk. This is one of the key principles underlying a barrier approach to risk management (refer to Module 7).

An exposure pathway consists of the following elements:

[2] The route-specific acceptance criteria presented in Tables 4.16 to 4.18 may be of use in determining conservative criteria appropriate to high and medium density residential use.

- a source and mechanism for release
- storage and/or transport media (more than one may apply, e.g. soil and air)
- an exposure point (where the receptor comes in contact with the contamination)
- an exposure route (e.g. inhalation).

The identification of potentially complete exposure pathways depends heavily on the development of a reliable conceptual model of the site, including consideration of site users and their activities and the fate and transport of contaminants (refer to Module 3 for further discussion of the development of a conceptual model for a site).

For example, where a former service station site is redeveloped for residential use, exposure pathways may include (depending on the specific contaminant):

- inhalation of volatiles, particularly benzene, in indoor air as a result of soil contamination beneath the building
- ingestion of contaminated soil that may be exposed in the vicinity of the house
- dermal contact with contaminated soil that may be exposed in the vicinity of the house
- consumption of home-grown produce.

The exposure pathways considered in developing soil screening criteria for each of the land uses/receptors are summarised in Table 4.3.

Even when an exposure pathway is potentially complete, equal weight should not necessarily be placed on each pathway. Exposure by consumption of home-grown produce and inhalation of volatiles rely on cross-media transfer of contaminants. Modelling the fate of contaminants, and in this case, the concentration in home-grown produce or indoor air, is invariably uncertain. Estimates of exposure via these routes can be refined using direct measurements of the contaminant concentrations in the media of concern.

For example, in the case of residential use where information on soil and groundwater concentrations is available, the exposure pathways that may be quantified with the most certainty are ingestion and dermal contact, followed by produce consumption and inhalation of volatiles. In the context of paved industrial or commercial uses, inhalation of volatiles is frequently the only potentially complete exposure pathway and therefore should be considered despite the uncertainty involved.

Similarly, in most cases exposure to contaminated building dust in living areas resulting from contaminated soil associated with a petroleum release, is not a significant contributor to the risk to a site user. Key factors associated with this include:

- petroleum-related contaminants generally do not exhibit higher toxicity via the inhalation route
- volatilisation results in loss of many hydrocarbons from dust
- many petroleum releases occur in the sub-surface and many sites are paved reducing the potential for generation of contaminated dusts.

Table 4.3 Summary of exposure pathways

Exposure Pathway	Agricultural		Residential		Industrial		Maintenance workers	
	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface	Surface	Sub-surface
Ingestion of contaminated soil	√		√		√		√	√
Consumption of produce	√		√					
Dermal absorption	√		√		√		√	√
Inhalation of volatiles (indoors)	√	√	√	√	√	√	√	√
Inhalation of volatiles (outdoors)	√	√	√	√	√	√	√	√
Inhalation of particulates	√		√		√		√	√

In most cases building dust is not sampled at a Tier 1 level and hence criteria for building dust have not been derived. Building dust can be assessed at a Tier 2 level if required.

As discussed earlier, leaching of contaminants from soil to groundwater has been considered in the development of Tier 1 soil acceptance criteria for the protection of groundwater quality. Site users or users of groundwater in the vicinity of the site may be exposed to contaminants in soil following leaching to groundwater and transport to a point of use (e.g. bore used for potable supply). The Tier 1 soil acceptance criteria for the protection of groundwater are expected to be of most use in assessing the future impact of residual soil contamination on groundwater quality. The Tier 1 soil acceptance criteria for the protection of groundwater quality are presented separately from the Tier 1 soil acceptance criteria developed on the basis of exposure to contaminated soil.

Inhalation of particulates is noted in Table 4.3 as a complete exposure pathway however, in most circumstances the contribution of this pathway to the overall exposure is negligible. The exception to this is exposure scenarios involving high concentrations of suspended particulates and limited exposure via other routes, and contaminants exhibiting low volatility and significantly higher toxicity via the inhalation route (e.g. arsenic, hexavalent chromium). None of the contaminants considered in deriving Tier 1 soil acceptance criteria satisfy these conditions. On this basis, exposure via inhalation of particulates has not been considered further.

4.4 Toxicity assessment

Toxicity evaluation involves an assessment of the possible effects associated with exposure to a given chemical or mixture of chemicals, and the level of exposure results in no appreciable risk of an adverse effect. The following section summarises the dose response factors used in derivation of the Tier 1 soil acceptance criteria.

4.4.1 Overview

Toxicity assessment involves an assessment of the possible effects associated with exposure to a given chemical and the level of exposure that may be tolerated without appreciable risk of adverse effects. Dose response factors are used to characterise the relationship between the level of exposure and the likelihood of adverse effects.

Information on the effects of chemical contaminants on the human body is generally limited and therefore a degree of uncertainty is associated with any quantitative assessment of the relationship between exposure or dose, and the likelihood of an adverse effect. Information is typically drawn from epidemiological studies (of disease rates in human populations as a result of occupational or environmental exposure to chemicals and from animal studies conducted under laboratory conditions. The results of a range of cellular tests (e.g. mutagenicity assays) and metabolic/mechanistic studies are frequently used as supporting information, particularly in understanding the relevance of results from animal studies to assessing the risk associated with human exposures.

Information on the effects of chemical exposure and the level of concern is invariably incomplete, and therefore extrapolation is required to assess the risk associated with most contaminated land scenarios. For example:

- information on the effects associated with relatively high doses is extrapolated to estimate the effects associated with the very low doses typical of environmental exposures
- information on the effects of chemicals in laboratory animals is extrapolated to estimate the effects in humans
- information on the effects associated with short-term exposures is extrapolated to estimate the effects of long-term exposure.

To ensure protection of public health, in deriving dose response factors, safety factors are incorporated to account for the uncertainty introduced by extrapolation.

4.4.2 Dose response factors

Dose response factors may be defined to relate exposure or dose and the likelihood of an adverse effect for each chemical. While the relationship between dose and effect is complex, contaminants may be divided into two broad groups based on simplifying assumptions regarding the nature of the dose response relationship, as follows:

- contaminants that exhibit no threshold in the dose response relationship
- contaminants exhibiting a threshold dose response relationship

There is considerable debate regarding the nature of dose response relationships. For the purposes of deriving Tier 1 soil acceptance criteria, an approach broadly consistent with the NZDWS (as a precedent indicating Ministry of Health policy) has been adopted. In general, carcinogenic contaminants exhibiting genotoxicity have been assessed using a non-threshold dose response model (as characterised by the Slope Factor, see below) and all other contaminants have been assessed using a threshold dose response model (as characterised by the Reference Dose, see below).

The relevant dose response factors may be defined as follows;

- **Slope Factor**

A plausible upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime. The slope factor is used to estimate an upper-bound probability of an individual developing cancer as a result of a lifetime of exposure to a particular level of a potential (genotoxic) carcinogen.

- **Chronic reference dose (RfD)**

An estimate (with uncertainty spanning perhaps an order of magnitude or greater) of a daily exposure level for the human population, including sensitive sub-populations, that is likely to be without an appreciable risk of deleterious effects during a lifetime. Chronic RfDs are specially developed to be protective for long-term exposure to a compound.

The existing dose-response data are generally limited and are extrapolated to determine exposure levels that are consistent with a very low risk (typically 10^{-4} to 10^{-6}) to determine acceptance criteria. Published dose response factors are generally conservative, and incorporated safety factors to account for the inherent uncertainties in such estimates.

The dose response factors adopted for each chemical of concern are summarised in Tables 4.4 and 4.5.

Table 4.4 Dose response factors for carcinogens

Contaminant	Source	Slope Factor $(mg/kg/d)^{-1}$	
		Ingestion	Inhalation
Benzene	USEPA (1995)	0.029	0.029
Benzo(a)pyrene	USEPA (1995)	7.3	7.3

Table 4.5 Comparison of dose response factors for non-carcinogens

Contaminant	Source	Oral reference dose (mg/kg/d)	Inhalation reference concentration (mg/m^3)
Toluene	USEPA[3]	0.2	0.4[1]
Ethylbenzene	USEPA[3]	0.1	0.1
Xylene	USEPA[3]/NZDWS[7]	2	0.3[2]
C7 to C9 TPH	TPHCWG	5	17.5
C10 to C14 TPH	TPHCWG	0.1	0.35
C15 to C36 TPH	TPHCWG	1.5	5.3
Naphthalene	USEPA[8]/ASTM[6]	0.004	0.014[4]
Pyrene	USEPA	0.03	0.11[5]

1. Equates to oral reference dose.
2. Equates to an intake of 0.09 mg/kg/d.
3. USEPA, 1995.
4. Equates to an intake of 0.004 mg/kg/d.
5. Equates to an intake of 0.03 mg/kg/d.
6. ASTM, 1995
7. MoH, 1995
8. USEPA, 1991a

Dose response factors have been nominated by a range of agencies for the contaminants of most concern in the context of petroleum contaminated sites. The USEPA have nominated the most comprehensive range of dose response factors, and these have been selected as a starting point for the derivation of Tier 1 soil acceptance criteria. The USEPA dose response factors were reviewed for consistency with the dose response factors implied in the NZDWS; (where the NZDWS suggest a significantly more stringent value this value was adopted.

Information on dose response factors for the petroleum hydrocarbon mixtures as measured by the TPH analysis is limited and therefore reference is made to the work of the Total Petroleum Hydrocarbons Criteria Working Group (refer Appendix 4B for further details).

A summary of the health effects associated with each of the contaminants of concern and the basis for the derivation of dose response factors is presented in Appendix 4L.

4.4.3 Assessment of PAH mixtures

PAHs are generally present in the environment as complex mixtures. In order to streamline the Tier 1 assessment of PAH contaminated soil, acceptance criteria have been derived for three representative PAH compounds: naphthalene, pyrene and benzo(a)pyrene. One of the primary concerns associated with the assessment of PAHs is the carcinogenic hazard posed by benzo(a)pyrene and other heavier PAH compounds.

The relative potency of the carcinogenic PAHs may be described using toxic equivalence factors (TEFs). The TEF for a specific compound may be defined as the ratio of the carcinogenic potency of the compound to that of benzo(a)pyrene (i.e. TEF <1 indicates a compound is a less potent carcinogen than benzo(a)pyrene). The TEFs may be used to determine the slope factor for each of these compounds based on the slope factor for benzo(a)pyrene. The TEFs are shown in Table 4.6 and are based on USEPA guidance. The TEF approach takes into account the differing potencies of carcinogenic chemicals, allowing acceptance criteria to be determined in terms of benzo(a)pyrene equivalent concentration.

Oral and inhalation slope factors for the carcinogenic PAHs (normalised to benzo(a)pyrene using TEFs) range from 7.3 $(mg/kg/day)^{-1}$ for benzo(a)pyrene to 0.073 $(mg/kg/day)^{-1}$ for chrysene.

As a first approximation, as part of a Tier 1 assessment, the significance of soil contamination by carcinogenic PAHs may be assessed by using the TEFs as follows:

- develop risk-based criteria for benzo(a)pyrene
- measure PAH concentrations in soil
- estimate the benzo(a)pyrene equivalent concentration based on the measured PAH concentrations in soils and published TEFs
- compare benzo(a)pyrene equivalent concentrations with risk-based criteria.

The benzo(a)pyrene equivalent concentration may be conceptualised as the concentration of benzo(a)pyrene that would give the same risk as the mixture of carcinogenic PAHs.

This approach is based on the simplifying assumption that in establishing Tier 1 acceptance criteria the differences in the fate and transport characteristics of each of the carcinogenic PAHs are of secondary importance (compared to differences in the cancer potency of each carcinogenic PAH). Therefore, this approach should only be used for a preliminary evaluation.

Table 4.6 Toxic equivalence factors (TEF) for carcinogenic PAHs

Chemical	TEF
benzo(a)pyrene	1
benzo(a)anthracene	0.1
benzo(b)fluoranthene	0.1
benzo(k)fluoranthene	0.1
chrysene	0.01
dibenz(a,h)anthracene	1
indeno(123-cd)pyrene	0.1

Source: USEPA, 1993

4.5 Exposure assessment

Exposure assessment is directed toward quantifying the amount of chemical each of the receptors is likely to be exposed to, for use in conjunction with dose response factors from the toxicity assessment to estimate the likelihood of adverse health effects. In deriving Tier 1 soil acceptance criteria, exposure assessment involves relating a tolerable level of exposure to contaminant concentrations in soil, including consideration of indirect exposure routes.

4.5.1 Overview

The objective of the exposure assessment element of risk assessment is quantification of the exposure likely to be experienced by receptors, in this case, site users. In the context of the derivation of Tier 1 soil acceptance criteria, the objective of exposure assessment is to determine contaminant concentrations in soil that would result in a tolerable level of exposure. Exposure assessment involves:

- estimation of contaminant concentrations in each of the media (e.g. soil, air, water, produce) to which receptors may be exposed, that correspond to the nominated level of tolerable exposure
- estimation of contaminant concentrations in soil that may give rise to the tolerable contaminant concentrations in each of the exposure media (e.g. air, groundwater, produce).

The overall approach adopted for exposure assessment in derivation of the Tier 1 soil acceptance criteria is based on the USEPA protocol for the development of Preliminary Remediation Goals (USEPA, 1991), which is consistent with the approach used for the development of soil acceptance criteria for the timber industry (MfE/MoH, 1993) and for the assessment of gasworks sites (MfE, 1996). In particular, the exposure factors adopted for the derivation of the Tier 1 soil acceptance criteria have been modified to reflect New Zealand conditions and policy. In addition, the fate and transport modelling components of this section differ from the approach adopted by the USEPA for the development of Preliminary Remediation Goals.

Exposure assessment depends on assumptions regarding a range of exposure factors. In practice, there is uncertainty regarding the value of many exposure factors (e.g. the quantity of soil ingested by children), whereas other exposure factors vary through the population (e.g. body weight). Most commonly, reasonably conservative assumptions are used to account for such uncertainty and variability, thus ensuring protection of public health. However, the use of conservative point estimates (e.g. for soil ingestion rate, exposure frequency, exposure duration) in calculations involving many such parameters can result in a compounding conservatism. Further, information on the level of conservatism inherent in the acceptance criteria is lost.

Probabilistic techniques, such as Monte Carlo analysis, allow the variability and uncertainty in exposure factors to be considered. Monte Carlo analysis allows the estimated acceptance criterion to be expressed in terms of a probability distribution which accounts for the variability and uncertainty in the exposure factors. A single value for use as a Tier 1 Acceptance Criterion may be selected from the probability distribution based on the level of conservatism desired.

Incorporation of probabilistic techniques in the derivation of Tier 1 soil acceptance criteria may be considered once the required information becomes available.

4.5.2 Environmental settings

The environmental setting of a site affects both the fate and transport of contaminants and the sensitivity of the likely receiving environments. In the context of deriving of Tier 1 soil acceptance criteria, the following are key factors in the environmental setting:

- soil type (and properties)
- depth to the contamination
- depth to groundwater (for deriving screening criteria for the protection of groundwater quality)
- land use (as discussed in Section 4.3.2), including the nature of buildings at the site.

Other characteristics associated with the environmental settings are of greater importance in assessing the significance of groundwater contamination, for example, the quality and yield of the aquifer and the proximity to surface waters. The significance of these issues and their role in determining the requirements for a Tier 1 assessment are discussed in more detail in Modules 1 and 5.

The sensitivity of the surrounding environment may be considered as part of the environmental setting. However, with the exception of off-site transport via groundwater, the impact of soil contamination on the surrounding environment e.g. terrestrial ecosystems on adjacent land, is unlikely to be limiting. Where a petroleum contaminated site is located adjacent to a particularly sensitive environment, e.g. pristine national park area, specific consideration of possible off-site impacts other than that associated with groundwater may be required (refer to Section 4.6 for guidance regarding the assessment of ecological impact at a Tier 1 level).

Tier 1 soil acceptance criteria have been derived for a range of land uses, as described earlier, and a range of depths to the contaminated soil layer. Three depths to contamination were selected for deriving Tier 1 soil acceptance criteria:

- **Surface soils, <1 metre**

  Surface contamination is of primary concern in health risk assessment due to the range of exposure routes that are likely to be complete. Normal digging activities, say, in a residential context, are unlikely to extend beyond a depth of 1 metre. The root zone of most vegetables is confined to a depth of less than 1 metre.

- **Subsurface soils, 1 - 4 metres**

  The depth to contamination has an important impact on the rate of volatilisation of contaminants and on the relevant exposure pathways. Where contaminated soil is located at depths greater than 1 metre it is assumed that normal users of the site are unlikely to come in direct contact with contaminated soils. Hence Tier 1 soil acceptance criteria for this depth range do not consider ingestion of soil, dermal adsorption and home-grown produce consumption. The roots of fruit trees may extend to depths greater than 1 metre; however, uptake of contaminants by fruit trees is generally low compared to that by vegetables.

- **Depth soils, >4 metres**

  Most underground storage tanks are likely to extend to approximately 3 metres below the surface. Therefore, following tank removal and excavation of packing sand, the depth to the base of the excavation is likely to be in the order of 4 metres. Hence, criteria developed on this basis are likely to be of use in validating tank removal excavations.

In order to properly account for source depletion in volatilisation modelling it is necessary to make an assumption regarding the thickness of the contaminated zone. For the purposes of deriving Tier 1 soil acceptance criteria, a thickness of the contaminated soil layer of 2 metres has been assumed throughout.

The depth to groundwater affects the extent of attenuation of contaminants leached from the contaminated zone. For the purposes of deriving screening criteria indicating the need to monitor groundwater quality (for the protection of groundwater), the following depths to groundwater from the ground surface have been used in conjunction with the range of depths to the contaminated soil layer outlined above:

- to 4 metres (with surface soils)
- to 8 metres (with surface soils and subsurface soils)
- > 8 metres. (with surface, subsurface and depth soils).

Soil type (and other properties such as moisture content) has a significant impact on the rate at which contaminants may volatilise from soil, and particularly on the rate of diffusion through the soil column may occur. In order to account for the range of conditions likely to be encountered across New Zealand, and minimise the need to proceed to a more detailed level of risk assessment because of conservative assumptions regarding soil properties, eight general soil types have been selected for the derivation of screening criteria:

- sand, silty sands
- silts, sandy silts, clayey sands
- silty clay, sandy clay
- clay
- pumice
- peats and other highly organic soils

Two of the eight soil types are for derivation of groundwater criteria only

- fractured basalts
- gravels.

Fractured basalts and gravels are expected to hold very low residual levels of contaminant on a bulk basis, due to the nature of the material. For example, recovery of a sample of clean gravel and analysis for BTEX, say, does not give a result that is comparable with other soil analyses. Therefore, in terms of volatilisation modelling, fractured basalt and gravels have only been considered in the development of groundwater quality acceptance criteria (i.e. soil criteria based on volatilisation have not been included for fractured basalt and gravel).

Fractured basalts and gravels are rarely found extending from the surface to below the contaminated zone. Rather, they are frequently overlain by a less permeable material. Therefore, a profile incorporating a 1-metre surface layer of silty clay or silt has been assumed in the case of both fractured basalt and gravels.

The soil types listed above have been selected as representative of most areas in New Zealand where a significant number of petroleum handling facilities are likely to be found. Clearly there will be sites where the soil profile does not coincide with any of the selected soil types, in which case the nearest conservative alternative may be used to complete a preliminary assessment.

Table 4.7 presents representative properties for each of the selected soil types. The properties presented are for soils typically at depths greater than 0.5 metre (i.e. surface soils, such as the horizon, in which an elevated organic matter content may be expected are not included). Further, the selected moisture contents are designed to reflect gravity-drained soils where the immediate effects of capillary rise from groundwater surface evaporation are minimal.

4.5.3 Exposure concentration estimations

4.5.3.1 Overview

Many of the constituents of petroleum are relatively mobile in the soil environment and exposure may occur by contact with media other than that originally contaminated, i.e. contaminated soil. In order to derive Tier 1 soil acceptance criteria protective of human health it is necessary to establish the relationship between contaminant concentrations in soil and those in other media to which site users may be exposed. In terms of petroleum contaminated sites, estimating contaminant concentrations at the point of exposure is one of the most critical elements of the risk assessment. To do this, it is necessary either to directly measure contaminant concentrations at the relevant point or to predict the fate and transport of contaminants. Clearly, direct measurement is preferred in most cases. However, this is often not possible or practical (e.g. a house has not yet been built on a former service station site).

For the purposes of a Tier 1 assessment, it is assumed that contaminant concentrations will be measured in soil and groundwater (if contamination is likely to have occurred, refer Module 1), but not in other media such as ambient air or produce. Acceptance criteria for other exposure media, such as indoor air and produce, are presented in Appendices 4J and 4H of this module.

As part of the development of Tier 1 soil acceptance criteria, an estimate of the relationship between contaminant concentrations in different media is required for the following exposure pathways:

- **Inhalation of volatiles**

  An estimate of the contaminant concentration in indoor air and outdoor air, based on the concentration in soil is required to derive Tier 1 soil acceptance criteria.

- **Consumption of home-grown produce**

  An estimate of the uptake of contaminants by produce, based on the contaminant concentration in soil, is required.

- **Soil to groundwater pathway**

  An estimate of the relationship between soil concentrations and groundwater concentrations based on leaching of contaminants, is required in deriving Tier 1 soil acceptance criteria protective of groundwater quality.

Table 4.7 Soil properties for volatilisation modelling

Soil Type	Example	Air filled porosity (unitless)	Water filled porosity (unitless)	Total porosity (unitless)	Organic carbon content[a] (%)	Bulk density (tonne/m^3)	Capillary fringe thickness (m)
Sand, silty sand (SM)	Recent (R), Yellow brown sands (YBS)	0.26	0.12	0.38	0.3	1.9	0.05
Silts, sandy silts (ML, MH), clayey sand (SC)	Yellow grey earths (YG), Yellow brown earth (YB)	0.18	0.27	0.45	0.3	1.9	0.3
Silty clay (CL), sandy clay (MH, CL)		0.06	0.44	0.5	0.3	1.8	0.8
Clay (CH)[(1)]		0.02	0.48	0.5	0.3	1.8	1
Pumice	Pumice sands (YBP)	0.2	0.35	0.55	0.5	1.7	0.5
Fractured Basalts		0.08	0.03	0.11	<0.1	2.4	0.05
Peats and other highly organic soils (Pt)		0.23	0.23	0.46	12	1.6	0.3
Gravel (GW, GP)		0.25	0.03	0.28	<0.1	2	0.05

Note

1: The soil properties adopted for clay are designed to reflect a clay of very low permeability and high moisture content. Where there is uncertainty regarding the permeability and moisture content, or where the soil structure results in significant secondary porosity (particularly in near surface soils), the Tier 1 soil acceptance criteria for silty clay may be used as an alternative.

(a) Organic carbon content values for shallow soils at depths greater than 0.5 m are from the New Zealand National Soil Database run by Landcare Research.

4.5.3.2 Volatilisation

The relationship between contaminant concentrations in air within the breathing zone indoors and outdoors and the concentration in soil is described using the Volatilisation Factor (VF), which is defined as follows:

$$\mathbf{VF = (Concentration\ in\ air\ (mg/m^3)\ /\ Concentration\ in\ soil\ (mg/kg))}$$

The Volatilisation Factor is a function of soil and contaminant properties, the depth and thickness of contamination and the building or outdoor air characteristics. The Volatilisation Factor is not valid when non-aqueous phase hydrocarbons form; at this point the assumed linear equilibrium relationships become invalid as the contaminant concentrations in the vapour phase near the source (which control the rate of transport) reaches a maximum. This is a significant limitation of most volatilisation models. The point at which separate phase hydrocarbons begin to form is dependent on the soil and product type (including the extent of weathering) and is therefore site-specific. At most petroleum release sites some separate phase hydrocarbons may be expected to be present as a residual trapped in the soil matrix, if not floating on groundwater.

Notwithstanding this limitation, the assumption of a linear partitioning relationship as part of the volatilisation modelling is conservative as it will tend to overestimate the rate of volatilisation where residual separate phase hydrocarbons are present.

The impact of residual separate phase hydrocarbons on the volatilisation modelling should be considered in greater detail as part of a Tier 2 assessment.

A range of models for assessing the transport of volatile contaminants has been developed. However, considerable uncertainty remains and development continues. The fate and transport of volatile contaminants in the subsurface is complex, involving a wide range of processes, few of which are well understood. Most of the available models consider only a small subset of the fate and transport processes actually occurring and are based on simplified conceptual models of contamination (e.g. uniform contaminant concentrations through the contaminated zone).

Limited data is available with which to validate the volatilisation models currently used. While no peer-reviewed validation results were identified, non-peer reviewed and anecdotal information suggests the models may significantly over-predict or slightly under-predict volatilisation, depending on the site-specific conditions. One of the key factors affecting volatilisation is thought to be biodegradation in the unsaturated zone, which can vary significantly between sites. Significant research efforts are directed toward resolving this issue, and it is expected that further refinements to the existing volatilisation models and new models will be developed to account for biodegradation and other processes. Consideration may be given to reviewing the derivation of Tier 1 soil acceptance criteria as significant new information emerges.

Two models have been used in derivation of the Tier 1 soil acceptance criteria, as follows;

- **Modified Jury Behaviour Assessment Model (BAM)**

  Jury et al, (1983, 1984) developed a model for volatilisation of contaminants from surface soils, accounting for the boundary layer resistance associated with transport into the bulk air. The original Jury model is limited in that it does not account for diffusion from sub surface soils, or transport into indoor air. Modification of the Jury model involved substituting the original boundary condition for the governing differential equation which described the boundary layer resistance (air phase), for one incorporating the resistance to transport through the overlying soil, in the case of subsurface soils, and transport through the building foundations for indoor air. This does not alter the form of the Jury solution. One of the principal advantages is the ability of the Jury model to account for source depletion in a manner consistent with the conceptual model. A disadvantage of the Jury model is the complexity of the equations.

  The Jury model has a further advantage of being more flexible in accounting for losses by leaching and biodegradation (which have been neglected for the purposes of deriving Tier 1 Acceptance Criteria). Losses by leaching and biodegradation may be reasonably incorporated as part of a Tier 2 assessment using the modified Jury model.

  The modified Jury model has been used to model the diffusive transport of contaminants into indoor or outdoor air.

- **Johnson and Ettinger model**

  Johnson and Ettinger (1991) developed a model for estimating indoor air concentrations resulting from contaminated soil. The non-depleting (infinite) source model developed by Johnson and Ettinger was presented as an example in the ASTM Risk Based Corrective Action (RBCA) guidance. The Johnson and Ettinger model incorporates a simplification of the conceptual model that allows solution of a depleting source model. This model was modified to consider slab on ground construction (rather than a basement). The modified Johnson and Ettinger model is mathematically simpler than the Jury model but incorporates a simplification in the conceptual model, and criteria developed using the modified Johnson and Ettinger model are slightly lower than those developed using the Jury model.

  The Johnson and Ettinger model was used to estimate the advective/diffusive transport of contaminants from shallow soils (<1 metre) into indoor air.

  Details of the modified Jury and the modified Johnson and Ettinger models are presented in Appendix 4D.

4.5.3.3 Plant uptake

The primary concern associated with the uptake of contaminants by plants is the presence of contaminants in produce consumed by humans. The relationship between contaminant concentrations in soils and edible plant materials is highly site, plant species and contaminant specific, and therefore estimates of plant uptake are likely to be uncertain.

The relationship between contaminant concentrations in edible produce and the concentration in soil is described using the Plant Uptake Factor (PUF), which is defined as follows:

$$\text{PUF} = \frac{\text{Concentration in edible portion of plant (mg/kg)}}{\text{Concentration in soil (mg/kg)}}$$

A range of published correlations between plant and soil concentrations is available. Most correlations are empirical, assuming a linear relationship between the plant and soil concentrations and defining the ratio between the plant and soil concentrations in terms of K_{ow} or K_{oc} and the organic carbon content of the soil. The correlations between contaminant concentrations in soil and produce developed by Ryan et al (1988) together with fugacity partitioning relationships[3] (e.g. Patterson and Mackay, 1989) have been used in deriving Tier 1 soil acceptance criteria. The results of modelling are also compared with published information on the uptake of PAH compounds by plants (e.g. Edwards, 1983). Further details of the plant uptake model assumed are presented in Appendix 4F.

The available plant uptake models are expected to overestimate the concentration of most petroleum related contaminants because:

- most petroleum hydrocarbons are readily degraded in the soil environment, particularly under conditions favouring biological activity such as those found in vegetable gardens (e.g. regular watering, fertiliser)
- significant losses by volatilisation are expected to occur within a period of, for example, a year
- enhanced degradation of contaminants may be expected in the plant root zone

[3] Fugacity based relationships are an alternative to convention equilibrium partitioning relationships that allow for the non-ideal behaviour of gas mixtures and solutions.

- the depth range of most interest in a vegetable garden context is the upper 200 - 300 mm, where losses by volatilisation and other mechanisms are likely to be most pronounced.

Given that Tier 1 soil acceptance criteria have been based on long-term exposure to contamination (e.g. 30 years for carcinogenic contaminants), the criteria based on plant uptake and consumption of home-grown produce are expected to be conservative. Benzene and other volatile contaminants are not expected to persist in the near surface soils (e.g. less than 0.5 metres shallower) within vegetable gardens for any significant period of time, and therefore exposure via the consumption of home-grown produce is expected to be negligible. Plant uptake has therefore only been considered in the derivation of Tier 1 soil acceptance criteria for the PAH compounds. A screening level assessment to determine contaminants that may be subject to significant uptake by plants, conducted by Ryan et al (1988), generally supports this conclusion (although they also suggest uptake and translocation of heavier PAHs such as benzo(a)pyrene would be limited).

4.5.3.4 Leaching

Leaching of contaminants from soil and its impact on groundwater quality has been considered in the derivation of Tier 1 soil acceptance criteria for the protection of groundwater quality. Such criteria may be used to assist in determining the possible future impact of residual soil contamination on groundwater quality, for example following removal of the main source of current groundwater contamination.

The relationship between contaminant concentrations in groundwater and the concentration in soil is described using the Leaching Factor (LF), which is defined as follows:

$$LF = \frac{\text{Concentration in groundwater (mg/L)}}{\text{Concentration in soil (mg/kg)}}$$

The modelling of contaminant transport by leaching from contaminated soil is outlined in Appendix 4E. First-order biodegradation has been assumed along with a simple box model for predicting dilution of contaminants in the groundwater. Very limited information is available regarding likely contaminant degradation rates in the unsaturated zone. Therefore a set of conservative degradation rates based on the available information (largely for degradation in the saturated zone) and professional judgement have been adopted (refer Appendix 4E). Less conservative degradation rates may be adopted on a site-specific basis where the necessary information is available.

4.5.4 Exposure estimation

Tier 1 soil acceptance criteria for the protection of human health have been based on an estimate of the reasonable maximum exposure (RME) on a particular site, (USEPA, 1989a). The goal of RME is to combine upper bound and average exposure factors in a manner such that the result represents an exposure scenario that is both protective and reasonable, one that is not the absolute worst case but represents a reasonable maximum exposure (USEPA, 1991b).

The approach for the exposure assessment and the development of the proposed health based-based acceptance criteria is based on the procedures developed by the USEPA (1989a, 1991c). In general, assumptions employed in the risk assessment are based on recommendations by the USEPA (1989a, 1991), information presented in Langley (1993) and precedents established in similar guidance for the timber industry (MfE/MoH, 1993) and for the assessment of gasworks sites (MfE, 1996).

The estimated exposure (or intake) is normalised for time and body weight and is generally calculated as:

$$\textbf{Intake} = \frac{\textbf{Concentration x Contract rate x Exposure frequency x Exposure duration}}{\textbf{Body weight x Averaging time}}$$

This equation may be rearranged to give health-based acceptance criteria on a route-specific basis as follows:

$$\textbf{Acceptance Criteria (Concentration)} = \frac{\textbf{Acceptable intake x Body weight x Averaging time}}{\textbf{Contact rate x Exposure frequency x Exposure duration}}$$

where

Acceptable intake = (Proportion of RfD assigned to contaminated soil) x (Reference Dose)

Note that the Acceptable Intake equation is only applicable to non-carcinogenic compounds or other compounds exhibiting a threshold-type dose response relationship. For contaminants with a threshold dose response relationship, it is assumed that no effect is likely to occur until the total exposure from all sources exceeds the Reference Dose. In contrast, contaminants exhibiting no threshold are assessed on the basis of the incremental risk associated with each exposure independently.

The use of a "proportion of RfD assigned to contaminated soil" in the equation is equivalent to adopting a target HQ for a specific exposure (independent of other exposures) of < 1.

The Acceptance Criterion equation may be further modified to account for multiple exposure routes.

As an alternative to deriving criteria based on the RME, probabilistic techniques such as Monte Carlo analysis can be used to account more realistically for variability and uncertainty (refer to Section 4.5.1). Monte Carlo analysis[4] would involve assigning a probability distribution to each parameter, which describes the uncertainty or variability in the estimate for each parameter. Monte Carlo analysis can then be used to return an estimate of the intake of a contaminant (which can be converted to an estimate of the risk) or the acceptance criterion in terms of a probability distribution. Then a Tier 1 Acceptance Criterion can be selected from the probability distribution based on an agreed level of conservatism (e.g. the acceptance criterion could be selected such that 95% of the population exposed would be subject to a risk less than the target level of risk).

The development of Tier 1 soil acceptance criteria using Monte Carlo analysis may be considered when additional information is available regarding the distribution of some exposure factors in New Zealand.

4.5.5 Exposure factors

4.5.5.1 General

The exposure factors adopted for the purposes of screening criteria development are consistent with those adopted in the revised *Health and Environmental Guidelines for Selected Timber Treatment Chemicals* and are in accordance with Ministry of Health policy.

For the purpose of developing soil screening criteria for agricultural and residential land use, two age groups have been considered:

- adults

[4] Monte Carlo analysis involves an interactive process of selecting values from each of a number of predetermined distributions characterising the input variables and combining the values according to pre-set mathematical formula (e.g. exposure equation) to give an output value until a probability distribution describing the output variable is defined.

- children (1-6 years)

In a residential context, children and adults may live at a given site and it often occurs that children may spend the majority of their childhood at one residence. On this basis it is assumed that the exposure period begins when the child is a toddler and continues through childhood to adult life. Adult exposure may notionally be considered to correspond to six to 30 years of age. The establishment of criteria based on exposure from six months to 30 years (i.e. child and adult exposure) will also be protective of adults exposed for 30 years. For those contaminants for which a non-threshold dose response model has been adopted, the lifetime average daily dose relevant for risk assessment reflects a weighted mean of childhood and adult exposures. Where a threshold dose response model has been adopted a year-averaged exposure is used to determine acceptance criteria, with children the limiting receptor group for residential and agricultural use[5].

The exposure parameters for children generally reflect those of a two-year-old child as soil ingestion is generally greatest at this time, whereas the exposure parameters for residents older than six years reflect those for adults.

The exposure factors adopted for the purposes of deriving Tier 1 soil acceptance criteria are summarised in Table 4.8.

Exposure via each of the pathways considered in deriving Tier 1 soil acceptance criteria, with the exception of inhalation of volatiles, is assumed to be constant with time, i.e. contaminant concentrations do not decrease with time. Depletion of the mass of contaminants in the contaminated soil layer results in decreasing indoor and outdoor air concentrations with time. It is therefore necessary to determine average indoor and outdoor air concentrations based on an assumed averaging time.

In the case of carcinogenic contaminants, it is appropriate to average the air concentration over the entire exposure period, e.g. 30 years, which is then, in turn, averaged to give a lifetime average exposure. For non-carcinogenic contaminants, attention is focused on chronic exposure. The USEPA define chronic exposure as exposure from seven years to lifetime (USEPA, 1989a), and given the use of chronic RfDs as the basis for Tier 1 soil acceptance criteria, the exposure assessment must focus on exposure over this period.

If exposure over a period of seven years is sufficient to be of concern with respect to human health, then averaging the indoor and outdoor air concentrations over a longer exposure duration is likely to underestimate the risk. For this reason, indoor and outdoor air concentrations for non-carcinogenic contaminants have been averaged over a seven-year period.

Use of a shorter averaging time for the indoor and outdoor air concentrations may be justified based on consideration of sub-chronic exposure. However, in practice sub-chronic RfDs are not generally available for the contaminants of concern. If indoor and outdoor air concentrations were averaged over a period of one year rather than seven years, to reflect sub-chronic exposure, and the chronic

5 Given chronic health effects may be experienced by children exposed to a substance over a period of months to years, if exposures to children and adults are combined for the assessment of non-carcinogenic health effects over, say, the 30 year exposure duration for a residential scenario, then the year averaged CDI for children would be underestimated, as would the likelihood of adverse health effects. In particular, the year-averaged CDI for children would be underestimated when the higher exposure rates experienced by children for, for example, six years, are combined with lower rates of exposure experienced by adults for a longer period of time, and expressed as a year-average over a period of, for example, 30 years. Consequently, the assessment of non-carcinogenic health effects for residential and agricultural land uses are based on a year average CDI for the most sensitive group (or the group with the highest weight-standardised exposure rate), e.g. children in the case of ingestion of contaminated soil, rather than averaging over the entire 30-year exposure.

RfDs were used to assess sub-chronic exposure in the absence of sub-chronic RfDs, then the resultant Tier 1 Acceptance Criteria would decrease by a factor of 2 - 2.5 for most of the non-carcinogenic contaminants of most concern. Given that sub-chronic RfDs would normally be expected to be less stringent than the chronic RfDs, the small difference in criteria based on averaging over one year compared to seven years suggests than consideration of subchronic exposure (i.e. averaging time of one year combined with a sub-chronic RfD) is unlikely to result in significantly more stringent criteria.

For the purposes of deriving soil acceptance criteria, the land uses have been defined as follows:

- **Agricultural use**

  Agricultural use includes all agricultural and horticultural uses, particularly those involved in the production of food for human consumption. Consideration is normally given to the protection of the general public by ensuring that soil contamination would not give rise to a concentration in produce that would cause a concern with respect to human health. Consideration is given to the protection of consumers of produce based on the assumption that residents and others may consume 100% of their produce requirements from a contaminated source.

  In addition, consideration is given to the protection of the health of residents at any farm property, assuming that residents may be exposed via the consumption of home-grown livestock and produce, and through more direct contact with the contaminated soil, e.g. ingestion of contaminated soil. It is assumed most houses do not have basements.

- **Residential Use**

  The residential scenario on which the guideline values are based is low density residential use, including rural residential, where a considerable proportion of the total amount of produce consumed is grown at the site. While fowl are sometime kept at residential premises, for the purposes of derivation of the guideline values no consideration has been given to uptake by livestock. If livestock for human consumption are kept at a site then consideration may be given to using the agricultural criteria, in the first instance. It is assumed that most houses do not have basements.

  It is acknowledged that many residential developments within urban areas effectively limit the amount of produce that may be grown, reducing exposure for some contaminants. Where a significant quantity of produce cannot be grown, consideration may be given to the adoption of site-specific criteria excluding the consumption of produce (or at least reducing the proportion assumed to be sourced from the site), based on the route-specific criteria presented in Tables 4.16 to 4.18.

- **Commercial/Industrial Use**

  The commercial/industrial land use is designed to reflect exposure conditions at a largely unpaved industrial site where workers may come in direct albeit incidental, contact with contaminated soil. This scenario is not designed to include consideration of workers actively involved in excavation or similar activities. Where a site is largely paved, higher contaminant concentrations may be acceptable, as outlined in the guidelines.

4.5.5.2 Agricultural

Protection of human health

Soil screening criteria have been developed on the basis of protection of human health, given maximum plausible or reasonable maximum case exposure assumptions (Table 4.8).

The major exposure assumptions are summarised below, using published typical average and upper bound values:

- exposure duration = 30 years, assuming exposure from 0 to 30 years of age, 6 years as child, 24 years as an adult.

  The exposure duration is based on the reasonable maximum time spent on the one site in a rural context based on USEPA (1989).

- exposure frequency = 350 days/year (USEPA, 1989a)

  Studies have shown that a child is likely to spend fewer than 200 days/year playing outside. However, Hawley (1985) estimated that 80% of indoor dirt is derived from local soil, meaning a child may be exposed indoors or outdoors.

Table 4.8 Summary of exposure factors

Exposure factor	Units	Agricultural		Residential		Commercial/ Industrial	Maintenance
		Child	Adult	Child	Adult	Adult	Adult
General:							
Body weight	kg	15	70	15	70	70	70
Exposure duration	years	6	24 (30 total)	6	24 (30 total)	20	20
Exposure frequency	days/year	350	350	350	350	240	50
Soil ingestion:							
Soil ingestion rate	mg/day	100	25	100	25	25	100
Dermal absorption:							
Area of exposed skin	cm^2	2625	4700	2625	4700	4700	4700
Soil adherence	mg/cm^2	1	1	0.5	0.5	1	1.5
Produce consumption:							
Produce ingestion rate	kg/day	0.13	0.45	0.13	0.45	NA	NA
Proportion of produce grown on-site	%	100	100	50/10(1)	50/10(1)	NA	NA
Inhalation:							
Indoor inhalation rate(2)	m^3/day	3.8	15	3.8	15	10(3)	10(3)
Outdoor inhalation rate(2)	m^3/day	3.8	20	3.8	20	10(3)	10(3)

Notes: 1. Alternative value more representative of behaviour in large urban centres.
2. Based on 24-hour period.
3. Based on 8-hour period

- body weight: child (1-6 years) = 15 kg (USEPA, 1991b)
  adult (7-31 years) = 70 kg ANZECC, 1992)
- soil ingestion rate: child (1-6 years) = 100 mg/day (ANZECC, 1992)
  adult (7-31 years) = 25 mg/day
- inhalation rate: child (1-6 years) = 3.8 m^3/day (Langley, 1993)

adult (7-31 years) = 20 m^3/day outdoors (ASTM, 1995)

= 15 m^3/day indoors

- exposed skin surface area child (1-6 years) = 2625 cm^2 (Langley, 1993)

  adult (7-31 years) = 4700 cm^2
- soil adherence: 1 mg/cm^2 allowing for soil contact typical of farming activities (USEPA, 1988)
- ingestion of produce:

  child (1-6 years)= 0.13 kg/day (Langley, 1993)

  adult (7-31 years) = 0.45 kg/day
- proportion of produce grown on site = 100% (MoH, 1995)

The assumed garden produce ingestion rates are based on the average daily consumption of fruit and vegetables derived from national dietary surveys, as presented in Langley (1993). By comparison, the fruit and vegetable ingestion rates proposed by other organisations are presented in Table 4.9.

Protection of plants and livestock

The impact of ground contamination on plant life and livestock may involve protection of human health for residents who may consume produce, protection of plant life (phytotoxicity), and maintenance of acceptance levels of contaminants in produce and livestock for sale.

Table 4.9 Summary of fruit and vegetable consumption data

		Amount consumed (g/day)				
Receptor	**Item**	**Australia [1]**	**USA [2]**	**USA [3,6]**	**Canada [4]**	**Netherlands [5]**
Child	Fruit	50				
	Vegetables	80				
	Total	130		270	125	150
Adult	Fruit	180	140			
	Vegetables	269	200			
	Total	449	340	540	250	290

Notes:
1 Langley, 1993
2 USEPA, 1991a
3 USEPA, 1989b
4 CCME, 1994
5 Shell , 1994
6 Sum of values for individual product items.

Given the nature of the contaminants of concern (e.g. volatile, readily degraded), and the depth range of concern for the protection of plant life and livestock in the agricultural context, criteria protective of human health are expected to be generally protective of these considerations.

4.5.5.3 Residential

Soil guidelines have been developed on the basis of reasonable maximum exposure assumptions. The major exposure assumptions are summarised in Table 4.8 with the following alterations

- soil adherence: 0.5 mg/cm^2 (USEPA, 1988)
- proportion of produce grown on site

  50% = rural residential

  10% = urban

A proportion of produce grown on site of 10% (i.e. urban site) has been used as the default for residential use (refer Table 4.10). Where a site may be regarded as a rural residential property, a higher proportion of produce grown on site may be used (refer Table 4.18).

4.5.5.4 Commercial/industrial

Human health is the primary on-site concern with regard to ground contamination where an ongoing industrial use is proposed. Where off-site transport of contaminants via soil movement, groundwater or surface water is likely, off site environmental or health impacts may be controlling. The human health-based acceptance criteria have been developed on the basis of reasonable maximum exposure assumptions.

The major exposure assumptions are summarised below:

- exposure duration = 20 years (USEPA, 1989b) (reasonable maximum time in one job corresponds to 90th percentile time since last job in the US). (Finley et al, 1994)
- soil ingestion rate = 25 mg/day (for workers not directly involved in excavation) (ANZECC, 1992)
- inhalation rate = 10 m^3/day (based on 8 hour working day) (Langley, 1993)
- skin surface area = 4700 cm^2, based on exposure of 24% of total adult body surface area (Langley, 1993)
- soil adherence = 1.0 mg/cm^2 (USEPA 1989)

The protection of human health is considered the primary on-site concern with regard to ground contamination where an ongoing industrial site use is proposed. Where contaminated areas are fully paved and where the integrity of the paving is maintained, the exposure to non-volatile soil contaminants should be eliminated. The effectiveness of pavement as a barrier to the exposure of workers to ground contamination, however, is highly dependent on the integrity and design of the pavement and on the nature of the underlying soils. Spreading and other transport of contaminated soil from areas where contaminated soil is unpaved or from areas of failed pavement may mean that protection against worker exposure to contaminated soil is likely to be significantly compromised. In addition, separate consideration must be specifically given to assessing the migration of volatiles through pavement and the subsequent exposure.

The acceptable contaminant concentration in soil on a paved industrial site may be controlled by exposures associated with ongoing maintenance of subsurface services or other subsurface works. Exposure associated with subsurface maintenance works may be effectively mitigated by the use of an appropriate site management plan requiring, for example, the use of protective clothing and equipment, whenever the integrity of the pavement is compromised by subsurface works, and the diligent clean-up of soil and repair of the damaged areas.

4.5.5.5 Maintenance

For each of the above site uses, with the possible exception of agricultural use, there is potential for significant human exposure to ground contamination associated with subsurface maintenance works, e.g. repair and replacement of services. While the duration of such works is generally much shorter than the other exposure scenarios considered, the rate of intake of various contaminants is likely to be much higher and such exposure may be significant where undertaken routinely by the same person.

In order to develop reasonable but protective soil guideline values goals for adult workers involved in subsurface maintenance, the following exposure factors have been assumed:

- exposure duration = 20 years, 90% upper bound for time spent in one job (USEPA, 1989b).
- soil ingestion rate = 100 mg/day (for workers directly involved in excavation) (GRI, 1988).
- exposure frequency = 50 day/year
- inhalation rate = 10 m^3/day (Langley, 1993)
- skin soil adherence = 1.5 mg/cm^2 (USEPA 1989)

The above assessment assumes that maintenance workers wear normal work clothes. The use of appropriate personal protective equipment may reduce worker exposure allowing work within areas with contaminant concentrations in excess of the proposed criteria.

The above exposure factors, combined with the modelling of volatilisation to indoor and outdoor air, is expected to provide a reasonable estimate of the exposure likely to occur as a result of maintenance activities involving direct soil contact and work both indoors and outdoors. In this case the volatilisation modelling conducted as part of the derivation of criteria for a commercial/industrial use may also be used in assessing exposure associated with surface maintenance activities.

Where maintenance activities involve significant excavation, e.g. repair of services, consideration must be given to the short-term exposure resulting from the disturbance of contaminated soil, the resulting enhanced volatilisation of contaminants and the accumulation of volatiles within an excavation. In order to address this scenario as part of the derivation of Tier 1 soil acceptance criteria, the volatilisation of contaminants into an excavation and the accumulation of volatiles within the excavation have been modelled. The New Zealand Workplace Exposure Standards (eight hour time-weighted average) have been used as the target air concentrations (given the relatively short duration of exposure) in order to determine tolerable soil concentrations (refer Appendix 4K).

Note that consideration of occupational exposure as part of the derivation of Tier 1 soil acceptance criteria does not negate the requirement to comply with the relevant occupational health and safety requirements and to conduct appropriate air monitoring when excavating in contaminated soils.

4.6 Ecological risk assessment

The assessment of ecological risk is discussed in general terms. A checklist is presented (Appendix 4I) to assist in identifying sensitive ecological receptors and complete exposure pathways as part of the Tier 1 assessment. Where a sensitive receptor and a complete exposure pathway is identified, then a more detailed Tier 2 assessment may be warranted.

4.6.1 General

The assessment of ecological impact associated with soil contamination is the subject of ongoing research and debate. Various techniques have been proposed for the development of ecologically-based soil screening criteria, but none of these have received a high degree of acceptance or support from the scientific community. Ecological risk assessment and the development of soil acceptance criteria protective of the terrestrial ecosystem is a highly complex task that is best conducted on a site-specific basis.

Most petroleum contaminated sites are not located within pristine environments for which a very high level of protection is required for the associated ecosystems. Most petroleum contaminated sites are located within a modified environment, and the primary requirements for ecological protection relate to the protection of off-site environment quality and to the associated ecosystems. Protection of on-site environmental quality only is required to protect functions relevant to the site use e.g. protection of native and introduced plants in the context of a residential use.

Given the difficulty in developing generic ecologically-based soil acceptance criteria and the lesser concern associated with the protection of on-site ecological functions (provided the off-site environment and associated ecosystems are protected), the Tier 1 ecological assessment consists of a careful review to determine:

- possible sensitive ecological receptors associated with the site
- possible exposure pathways for migration of the contaminant from the source to the ecological receptor. Possible exposure pathways should also be reviewed to ensure completeness.

Where a sensitive ecological receptor and a complete or potentially complete exposure pathway is identified, a further, more detailed evaluation of ecological risk should be undertaken as part of a Tier 2 site assessment.

To assist in the identification of sensitive ecological receptors and complete exposure pathways, a checklist has been prepared and is presented in Appendix 4I.

4.6.2 Identification of ecological receptors

A range of ecological receptors may be identified in the context of petroleum contaminated sites, including:

- on-site terrestrial ecosystems
- off-site terrestrial ecosystems
- off-site aquatic ecosystems.

The protection of off-site aquatic ecosystems can be readily addressed through consideration of groundwater quality (refer Module 5) and surface drainage from the site. The document

Environmental Guidelines for Surface Water Discharges from Petroleum Industry Sites in New Zealand developed by the OIEWG is of assistance in assessing the possible impact associated with discharge of surface run-off from the site. In most cases the impact of soil contamination on off-site aquatic ecosystems via surface drainage is expected to be relatively limited, particularly given that most soil contamination at petroleum release sites is present at depth. If an impact on off-site aquatic ecosystems via surface drainage is suspected, this should be assessed on a site-specific basis.

If, as part of the Tier 1 ecological assessment, the protection of on-site terrestrial ecosystems is noted as requiring further consideration, some of the ecological receptors that may be of relevance are as follows:

- soil micro-organisms
- soil organisms, such as earthworms
- plant life.

The requirement to protect each of these ecological receptors and the level of protection to be afforded must be carefully considered in the context of redevelopment of former petroleum handling facilities. Protection of these environmental receptors will usually also result in the protection of higher animals, particularly given the fact that higher animals are usually mobile and near surface petroleum contamination is often localised[6].

In the context of a more detailed ecological risk assessment (i.e. Tier 2 or 3), including the assessment of possible off site contamination, it may be necessary to consider a much wider range of receptors, reflecting, for example, food chain effects (refer Module Six).

4.7 Aesthetic considerations

General principles for the assessment of aesthetic impact are discussed. Aesthetic considerations are not addressed in the derivation of Tier 1 soil acceptance criteria, but rather on a site-specific basis.

4.7.1 General

Aesthetic impacts or impairment of the aesthetic qualities of a site are an important consideration in the management of contaminated land. There are several examples of sites that have been considered to be safe in terms of their possible impacts on human health and the environment, yet have been deemed to be unsuitable for a sensitive use on the basis of aesthetic impacts. In many cases aesthetic impact may be expected to be the most sensitive consideration associated with a diesel release.

Some of the primary aesthetic concerns associated with petroleum contaminated soil include:

- odour
- discolouration
- changes in soil structure
- adverse effects on gardens.

[6] Contaminants exhibiting strong bioaccumulation or biomagnification properties represent a possible exception to this generalisation, although most of the contaminants of concern at petroleum release sites are readily metabolised and do not strongly bioaccumulate or biomagnify.

Of the effects noted above, odour is possibly the most sensitive aesthetic effect and can be associated with contamination by relatively light fraction petroleum hydrocarbons or the heavier fractions. There are many examples where the most important indicator compounds (in terms of human health) associated with a gasoline release are not detected, having been lost to volatilisation or degradation, although more persistent, odorous compounds remain.

While it is not possible to completely define the petroleum constituents responsible for odour impacts in weathered fuel spills, based on the screening assessment of contaminants of concern and experience at a number of sites, some of the contaminants that may contribute significantly to odour include:

- xylene
- tri and tetra methyl benzene
- other highly alkyl substituted benzenes
- naphthalene.

It is also thought that in weathered heavy fraction petroleum hydrocarbon contamination, a range of highly branched alkanes and alkenes contribute to the associated odour.

Weathering can have an important effect on both the odour associated with petroleum contaminated soil and the specific contaminants associated with such an odour. For example, in relatively fresh gasoline contamination, it may be expected that many of the lighter (C_6 to C_{12}) branched alkanes and alkenes would contribute significantly to the odour. However, as the contamination weathers, most of the lighter alkanes and alkenes are lost due to volatilisation and biodegradation, leaving the more persistent compounds, as listed above.

Weathering of diesel contamination can result in contaminant concentrations that comply with all relevant health-based criteria, but which are still associated with an unacceptable aesthetic impact. Again, the alkyl substituted benzenes are thought to contribute to this odour which is characteristically sweet.

As the composition of a hydrocarbon mixture in soils changes with weathering or ageing, it is difficult to obtain a reliable, generic correlation between TPH concentrations in soil and aesthetic impact.

4.7.2 Criteria for the assessment of aesthetic impact

In the assessment of aesthetic impact a tension exists between:

- the need to assess sites individually due to the site-specific nature of odour and the aesthetic effects (for example, refer to Module 1 for a discussion of the relationship between soil type and maximum adsorbed phase concentrations), and
- the convenience and objectivity of establishing threshold soil concentrations for the protection of aesthetic quality. Assessment of aesthetic impact on a site-by-site basis relies on the “notoriously subjective” assessment of odour.

In assessing possible aesthetic impacts associated with contaminated soil, the following criteria must by satisfied for the site to be deemed acceptable:

- no perceptible odour associated with the soil (near to the soil)
- no perceptible discolouration of surface soil

- no impact on soil structure
- no sheen development on surface water including lakes, streams and harbours.

Aesthetic considerations are important when assessing the significance of soil contamination in the context of a sensitive land use, but these considerations are of much less importance for less sensitive land uses, e.g. industrial. While residents at a site may reasonably expect the aesthetic quality of the soil to be protected, in an industrial context, other aesthetic impacts associated with activities at the site mean that it would be unreasonable to seek a high level of aesthetic soil quality. Here, concern would be associated with possible off-site aesthetic impacts, but these are unlikely to be associated with petroleum contaminated soil within the site unless there is bulk soil movement or excavation.

Petroleum contaminated soil at depth may be of concern to human health, depending on the concentration of benzene and other volatiles, but is less of an aesthetic concern because it is largely unnoticed until disturbed by excavation or gardening. Therefore aesthetic concern is focused on the surface soils, rather than the subsurface soils, i.e. those soils with which residents are most likely to come in direct contact.

4.8 Tier 1 soil acceptance criteria and assessment of contamination

Tier 1 soil acceptance criteria based on the protection of human health are presented. Tier 1 soil acceptance criteria have been derived for a range of contaminants, land uses, soil types, and depths to contamination.

Soil screening criteria based on the protection of groundwater quality are presented for use in determining whether groundwater monitoring is required (refer Module 1).

General principles regarding the application of the Tier 1 soil acceptance criteria and assessment of soil contamination are discussed.

4.8.1 Tier 1 soil acceptance criteria

The Tier 1 soil acceptance criteria are presented in Tables 4.10 to 4.12. The criteria listed in Table 4.10 to 4.12 are based on consideration of the following exposure pathways:

- ingestion of soil
- dermal absorption, following direct contact with soil
- consumption of home-grown produce
- inhalation of volatiles (indoor and outdoor).

Tier 1 soil acceptance criteria for petroleum hydrocarbons are presented in Tables 4.13 to 4.15.

Aesthetic impact, protection of terrestrial ecosystems (including plant life) and protection of groundwater quality are not considered in deriving the Tier 1 soil acceptance criteria. Tier 1 soil acceptance criteria for the protection of groundwater quality are presented in Table 4.20 (refer Section 4.8.2).

Protection of produce for human consumption in an agricultural/horticultural context is considered via the assumption that 100% of the residents' fruit and vegetable requirements are supplied by the site.

Contaminant concentrations corresponding to the target risk level have been estimated for each exposure route, e.g. inhalation of indoor air, inhalation of outdoor air, ingestion of soil, consumption of home-grown produce, and dermal absorption (route-specific Tier 1 soil acceptance criteria).

The exposure associated with each exposure route may be considered, in general, to be additive. Therefore, it may be argued that the Tier 1 soil acceptance criteria should be based on the soil concentration corresponding to the target risk level based on the cumulative exposure from all exposure routes. This is readily done, using acceptance criteria for each individual exposure route. The position assumes that a contaminant acts in the same way, despite exposure occurring by different exposure routes. While this is true for some contaminants, many exceptions are noted.

In practice, one exposure route is frequently dominant (resulting in a route-specific acceptance criterion that is much lower than for other exposure routes). Therefore the Tier 1 acceptance criteria may be determined by selecting the lowest of the route-specific acceptance criteria. Where more than one exposure route is significant, the impact of the combined exposure is considered, and a note is included to this effect.

Acceptance criteria have been derived for maintenance workers (refer Appendix 4K) and compared to the criteria derived for the primary human receptors associated with each land use (Table 4.2). Therefore, the Tier 1 soil acceptance criteria for each land use include consideration of maintenance workers. The acceptance criteria based on protection of maintenance workers are presented in Table 4.19.

While Tables 4.10 to 4.12 present only the limiting criteria selected as the Tier 1 acceptance criteria, Tables 4.16 to 4.18 present each of the route-specific criteria. Not all of the exposure routes listed above will necessarily be complete at every site and therefore the Tier 1 acceptance criteria may be critically reviewed as part of the site specific application of the criteria. Where one or more exposure pathways included in the derivation of Tier 1 acceptance criteria are not complete, the route-specific acceptance criteria presented in Tables 4.16 to 4.18 can be used to determine alternative criteria.

In some cases, the volatilisation-based criteria calculated for sand, as presented in Tables 4.16 and 4.17, are less stringent than those calculated for sandy silt. This is contrary to the expected behaviour of hydrocarbons in the subsurface and reflects a minor anomaly in the modelling (refer Appendix 4D for further details). In order to account for the minor anomaly, the Tier 1 acceptance criteria for sand, presented in Tables 4.10 to 4.15, have been set equal to those nominated for silty sand. In any case, the difference between the criteria as calculated for sand and silty sand is relatively minor.

4.8.2 Tier 1 soil acceptance criteria for the protection of groundwater quality

Tier 1 soil acceptance criteria for the protection of groundwater quality have been developed. It is intended that the Tier 1 soil acceptance criteria for the protection of groundwater quality will help evaluate the possible future impact associated with residual soil contamination. In particular ,the Tier 1 soil acceptance criteria for the protection of groundwater quality are expected to be of use where direct measurement of groundwater quality is not likely to provide information of relevance to the assessment of possible future impact. For example, they may be used to assess the possible future impact on groundwater quality where groundwater quality has already been compromised and remediation works have been undertaken to remove most of the ongoing source of contamination. (Further discussion regarding the need for groundwater sampling is given in Section 5.2. of Module 5).

A wide range of factors may affect the migration of contaminants from soil to groundwater, including the presence of low permeability zones which may limit migration, or preferential pathways which may result in much more rapid migration of contaminants. Therefore the Tier 1 soil acceptance criteria for the protection of groundwater quality should not be rigidly applied; rather, judgement should be applied when they are used, accounting for site-specific conditions.

The soil screening criteria for the protection of groundwater have been developed by using:

- a simple, analytical leaching model
- the need to maintain potable quality groundwater
- a range of depths to contamination and depths to groundwater (as outlined in Section 4.5.2).

The Tier 1 soil acceptance criteria for the protection of groundwater quality are presented in Table 4.20.

Should contaminant concentrations exceed the soil acceptance criteria nominated in Table 4.20, consideration should be given to a more detailed evaluation of the possible fate and transport of contaminants and the beneficial uses for which the aquifer is to be protected.

4.8.3 Screening criteria for heavier fraction TPH based on PAHs

To assist in streamlining the site assessment process, screening criteria have been developed for the heavier fraction TPH, based on the likely PAH content in contamination associated with a diesel release. Where a product other than diesel results in heavy fraction TPH and PAH, contamination alternative criteria should be developed.

Screening criteria for heavy fraction TPH have been based on:

- typical PAH content of New Zealand diesel (Shell, 1994)
- acceptance criteria prepared for PAHs (refer Table 4.10 to 4.12)
- safety factors to account for weathering processes which are likely to result in greater degradation of the aliphatic and simpler aromatic compounds which comprise the majority of diesel fuels, compared to the PAHs, particularly the heavier PAHs.

Screening criteria for C_{10} to C_{14} TPH have been based on criteria for naphthalene (typically 3% of diesel). Screening criteria for C_{15} to C_{36} TPH have been based on pyrene (typically 0.4% of diesel).

Screening criteria for heavy-fraction TPH based on PAH are presented in Tables 4.21 and 4.22. For the purposes of deriving soil screening criteria for C_{10} to C_{14} TPH the surface soil criteria for naphthalene in sand have been adopted. The criteria for naphthalene nominated in Tables 4.10 to 4.12 are based, in part, on volatilisation and therefore are soil and depth dependent. The application of a safety factor to account for the differential degradation of the PAHs compared to other diesel components introduces additional uncertainty. The safety factor has been based on professional judgement.

Safety factors may be modified pending receipt of information on the impact of weathering on the composition of diesel. The criteria presented for C_{15} to C_{36} TPH depend on the reported low concentrations of heavier, carcinogenic PAH compounds in diesel. The typical analyses used for the derivation of criteria are consistent with other published information, indicating the concentrations of benzo(a)pyrene and other carcinogenic PAHs are very low (below detection limit).

The criteria presented in Table 4.22 are included in Table 4.13 to 4.15 (along with criteria developed based on the TPH CWG information). In general, soil acceptance criteria derived for the various TPH fractions using the TPHCWG information are significantly higher than the TPH screening criteria based on the PAH content of diesel, presented in Table 4.21. On this basis it is reasonable to not include an additional safety factor to account for the contribution of the non-PAH content of the diesel as the criteria presented in Tables 4.13 to 4.15 (based on the TPHCWG information) indicates this is relatively minor compared to the PAH contribution (assuming the safety factors presented above are reasonable).

4.8.4 Application of Tier 1 soil acceptance criteria

4.8.4.1 General

The Tier 1 soil acceptance criteria have been developed in a specific context and so their appropriateness should be critically reviewed in the context of specific site conditions as part of their application. Where differences arise, judgement may be used in assessing the significance of contamination. The route-specific soil acceptance criteria presented in Tables 4.16 - 4.18 may be a useful tool in assessing contamination where one of the assumed exposure routes is not applicable (e.g. plant uptake and consumption of home-grown produce in the context of proposals to redevelop a site for high density residential use). In some circumstances, a review of relevant exposure assumptions or exposure pathways may result in the adoption of alternative criteria that are protective of human health, without the requirement for further detailed calculations as would be required in the case of a formal Tier 2 evaluation.

The Tier 1 soil acceptance criteria have been developed for a range of scenarios in the context of specific land uses, soil types, depths to contamination and other characteristics describing the environmental setting. The Tier 1 soil acceptance criteria have been developed in the context of protection of human health and therefore provide a useful tool in assessing the significance of soil contamination. Other considerations that must be addressed in assessing a site include;

- protection of groundwater quality (refer Section 4.8.2 and Tier 1 soil acceptance criteria for the protection of groundwater quality)
- aesthetic impacts (e.g. odour, discolouration)
- ecological protection (e.g. plant life, terrestrial ecosystems).

The relevance of each of these considerations must be determined on a site-specific basis and incorporated in the assessment of contamination as appropriate.

The inhalation of volatiles and consumption of home-grown produce are exposure routes for which the derivation of Tier 1 acceptance criteria relies on modelling of the cross media transfer of contaminants. Such modelling is presently subjected to considerable uncertainty. The models used provide what is currently a "best guess" estimate of the actual exposure concentrations. It is felt that these models are conservative in most cases; that is to say it is felt that they overestimate the actual exposure concentrations. There is little data available to support or refute this assertion. Where information is available to suggest these exposure routes are either incomplete or less efficient than assumed in the derivation of Tier 1 soil acceptance criteria, Tables 4.16 to 4.18 may be used to assist in selecting alternative, less conservative criteria. Where direct measurements of the contaminant concentration in produce, indoor air, or soil gas are available, this information may be used to develop refined acceptance criteria. Appendix 4H presents target indoor air and produce concentrations and Appendix 4J presents acceptance criteria for soil gas that may be of use where direct measurements are available.

4.8.4.2 Averaging contaminant concentrations

The Tier 1 soil acceptance criteria have been based on the assumption of a largely unpaved, uniformly contaminated site. In practice, the distribution of petroleum related contamination is highly non-uniform both laterally and vertically, reflecting the nature of the layout of the sources and the subsurface conditions.

Given that chronic human exposure to ground contamination is the primary concern, it is reasonable to compare average contaminant concentrations, rather than the maximum measured concentration, with the proposed acceptance criteria. In estimating the reasonable maximum exposure, the USEPA (1991a) indicates that a "conservative estimate of the media average concentration over the exposure period" should be used. An exception to this general rule may apply in the case of criteria based on volatilisation and leaching modelling. Such modelling accounts, at least to some extent, for the attenuation of contaminants through otherwise uncontaminated soils above or below the contaminated zone for which simple averaging of contaminant concentrations may not be appropriate.

Where averaging is deemed as appropriate, the area across which contaminant concentrations are averaged should be selected on the basis of the typical area in which a person may spend most of their time. In the case of a residential land use, the averaging area may be selected as the area of a typical backyard.

In practice, insufficient information is likely to be available, as part of a Tier 1 assessment, to apply rigorous statistical techniques to determine the average contaminant concentrations. Where sufficient information is not available for the application of rigorous statistical techniques, judgement should be applied in selecting conservative estimates of the average concentration as outlined above. Selection of the maximum detected concentration as the basis for the assessment of risk should be avoided. For details of statistical methods relevant to the assessment of contaminated land refer to Gilbert (1987).

The application of statistical techniques to determine a conservative estimate of the mean concentration is problematic for the following reasons:

- variability of contamination with depth
- targeted sampling programs most often used in petroleum contamination assessment do not lend themselves to statistical analysis
- most environmental data is not normally distributed and therefore it is necessary to determine an alternative distribution for estimating confidence intervals on the mean.

Where sufficient information is available, the average contaminant concentration should be determined using appropriate statistical techniques, such as the 95th percentile confidence interval for the sample mean.

Where statistical analysis is used to determine a conservative estimate of the mean media concentration, a trade-off exists between the number of samples collected and the width of the confidence interval about the estimate of the mean. For example, where few samples are collected the confidence interval is relatively wide and a relatively low concentration must be targeted during remediation to ensure the upper confidence limit (UCL) is less than the criterion. Similarly where a greater number of samples are recovered, width of the confidence interval about the mean is reduced and a less conservative remediation strategy may be adopted.

Notwithstanding the general principle of assessing sites on the basis of average concentrations, it is necessary to ensure that any hot spots do not represent an unacceptable risk, e.g. localised area of free product acting as a source for ongoing groundwater contamination, highly contaminated soil that would pose an acute health risk to workers involved in subsurface works. The identification of hot spots relies on accurate site history information and appropriate sampling plan design. Gilbert (1987) provides information on sampling plan design for hot spot detection.

Given the limitations on averaging where acceptance criteria are derived using volatilisation or leaching modelling, and the limitations on the information typically available, as part of a Tier 1 assessment the following approach is proposed:

- identify the area in which significant contamination has been located
- average contaminant concentrations across the area in which broadly similar contaminant concentrations have been detected or a limited area across which a localised hot spot may be expected to have some impact.

For example, if contamination is identified in an aboveground storage tank yard, then it may be appropriate to average contaminant concentrations across the yard. If pathways other than volatilisation or leaching are controlling, then the approach to averaging across a defined area of interest as outlined above, may be appropriate.

While the above approach reflects the technical issues associated with averaging contaminant concentrations for comparison with the Tier 1 soil acceptance criteria, in some circumstances this will default to use of the maximum concentration depending on the numbers of samples collected.

4.8.4.3 Validation of excavations

The Tier 1 soil acceptance criteria may be used as clean-up criteria, defining the acceptable contaminant concentrations, for example, at the base of an excavation resulting from a tank removal. Invariably such excavations will be backfilled with material that differs from the surrounding natural material. Further, when such excavations are backfilled, the material is normally compacted in place, reducing the in situ porosity.

Such a scenario represents a variation from the assumed uniform soil conditions. As a first approximation, the Tier 1 soil acceptance criteria for the soil type that best describes the fill material should be used to validate the base of the excavation. Care must be exercised in selecting the Tier 1 soil acceptance criteria to use as the many fill materials do not conform neatly to the soil types selected. For example, when compacted a crushed rock material containing a significant fines content will often result in a relatively low porosity.

4.8.4.4 Heterogeneous soil profiles

The Tier 1 soil acceptance criteria are based on an assumed uniform soil profile. Where this assumption does not apply, judgement must directed to selecting the appropriate Tier 1 criteria. As a general rule, it is protective of public health to err toward a selection of the Tier 1 criteria corresponding to the more porous soil type in the profile. However, a layer of low porosity material in an otherwise high porosity profile can significantly reduce the emission of volatiles.

Layered soil profiles can be readily considered as part of the Tier 2 assessment, using the procedure outlined in Appendix 4D.

4.8.4.5 Alternative scenarios

Where one or more of the assumptions used to derive the Tier 1 soil acceptance criteria do not apply, the route-specific soil acceptance criteria presented in Table 4.16 to 4.18 may be of use in determining the significance of contamination. Common examples include:

- Vegetable gardens producing a significant proportion of the residents' total consumption are unlikely to be associated with medium to high density residential use. Tables 4.16 to 4.18 may be used to determine revised criteria for those contaminants for which produce uptake was a limiting consideration.
- Maintenance of surface paving dramatically reduces exposure to surface contamination. In a commercial/industrial context where paving is present, criteria based on direct contact with soil by normal site users may not apply. The release of volatiles would also be reduced, although the further volatilisation modelling would be required to determine the extent of this.

As discussed in Section 4.3.2, the Tier 1 soil acceptance criteria derived for commercial/industrial use do not necessarily apply in the case of sites for which ongoing use for petroleum handling is proposed. In the case of the volatilisation to indoor and outdoor air pathway it is appropriate to evaluate the significance of contamination in the context of the Workplace Exposure Standards, rather than the risk-based limits used for other land uses. This would require evaluation on a site-specific basis.

4.8.4.6 Use of Tier 1 acceptance criteria tables

The application of the Tier 1 acceptance criteria presented in Tables 4.10 to 4.22 is illustrated in Figure 4.2.

Tables 4.10 to 4.12 present the Tier 1 acceptance criteria based on a combination of relevant considerations for the protection of human health. Where the criteria based on a combination of all exposure pathways are considered inappropriate, criteria drawn from the tables presenting acceptance criteria for individual exposure routes may be used. The tables presenting the combined and route-specific Tier 1 acceptance criteria, and a description of their contents, are listed below:

Tier 1 Acceptance Criteria for Combined Pathways

- Table 4.10: Tier 1 acceptance criteria for Residential (all pathways)
- Table 4.11: Tier 1 acceptance criteria for Commercial / Industrial (all pathways)
- Table 4.12: Tier 1 acceptance criteria for Agricultural (all pathways)
- Tables 4.13 - 4.15: Tier 1 acceptance for TPH in diesel for Residential, Commercial/Industrial and Agricultural (all pathways).

Tier 1 Acceptance Criteria for Specific Exposure Routes and/or Receptors

- Table 4.16: Tier 1 acceptance criteria for Residential / Agricultural (volatilisation)

- Table 4.17: Tier 1 acceptance criteria for Commercial (volatilisation)
- Table 4.18: Tier 1 acceptance criteria for other pathways (soil ingestion, dermal, produce ingestion)
- Table 4.19: Tier 1 acceptance criteria for Maintenance and Excavation workers.

Tier 1 Soil Screening Criteria for the Protection of Groundwater Quality

- Table 4.20: Tier 1 acceptance criteria for protection of groundwater quality.

Basis for Tier 1 Acceptance for TPH as a Surrogate for PAHs

- Table 4.2: Soil screening criteria for heavy fraction TPH associated with diesel Example calculation sand soil type/surface soils
- Table 4.22: Soil screening criteria for heavy fraction TPH associated with diesel.

The process for applying the Tier 1 acceptance criteria presented in Tables 4.10 to 4.22 to the assessment of a petroleum contaminated site is described as follows (as outlined in Figure 4.2):

Step 1 - Comparison with Tier 1 Acceptance Criteria for Combined Pathways

Measured contaminant concentrations at a site may be compared with the Tier 1 acceptance criteria for BTEX and PAH chemicals for Residential, Commercial, Industrial and Agricultural land uses, as presented in Tables 4.10 to 4.12. Criteria for a number of soil types are presented, requiring the assessor to determine which of the generic soil types best reflect the conditions present on-site. A superscript on each criterion identifies the limiting pathway.

Tables 4.13 to 4.15 present Tier 1 acceptance criteria for TPH in diesel for all land uses. The intention is that the primary assessment of the condition of a site will be made using a comparison of TPH and BTEX concentrations with relevant criteria. The TPH criteria are intended primarily as an alternative approach where either BTEX or PAH analyses have not been undertaken. In the case of a diesel release, in the first instance TPH may be used as a surrogate measure of the risk associated with PAH contamination.

The criteria in Table 4.10 are based on produce consumption of 10% home-grown, consistent with a typical urban residential development. In the case of a rural residential development, a proportion of produce home-grown is more likely to be in the order of 50%. If a site may be regarded as rural residential, the assessor should proceed to Step 2.

If the contaminant concentrations in the soil on-site are less than the relevant acceptance criteria, then no further work is required on a human health risk basis. However, further consideration should be given to ecological assessment, aesthetic impact and to groundwater protection (refer Step 8).

It should be noted that criteria for pyrene are presented on the basis that it is a representative of lower volatility (compared to naphthalene) non-carcinogenic PAHs. Similarly, benzo(a)pyrene is considered as a representative of the carcinogenic PAHs in fuel. Refer to Section 4.4.3 for a discussion of benzo(a)pyrene equivalent concentrations and the use of Toxic Equivalent Factors (TEFs).

Step 2 - Review of Exposure Pathways

A review of exposure pathways relevant to the site should be undertaken. If the future use of a site is known, then based on the review of exposure pathways, some of the pathways considered in the derivation of the Tier 1 criteria presented in Tables 4.10 to 4.15 may not be complete and therefore less stringent criteria may be applicable. For example, it may be known that a residential site will become a block of flats where consumption of home-grown produce is not likely to be a relevant pathway.

Pathways considered in the derivation of Tables 4.10 to 4.15 include:

- volatilisation
- protection of maintenance and excavation workers for surface soils and soil at depths of 1 - 4 metres
- soil ingestion
- dermal contact
- consumption of home-grown produce.

Tables 4.16 to 4.19 present Tier 1 acceptance criteria derived for individual pathways or exposure scenarios. For residential properties, produce ingestion must be selected for the appropriate scenario: urban residential (10% home-grown produce), rural residential (50% home-grown produce). Agricultural sites have been derived on the basis of 100% home-grown produce.

After all of the relevant pathways have been reviewed, the lowest route-specific acceptance criteria is selected for comparison with the contaminant concentrations[7].

Step 3 - TPH Surrogates for PAH Contamination in Diesel Fuel

The Tier 1 acceptance criteria presented in Tables 4.13 to 4.15 include consideration of the use of TPH as a surrogate measure of the risk associated with PAH contamination of soil resulting from diesel fuel. The Tier 1 acceptance criteria for TPH as derived in Tables 4.21 and 4.22 and as presented in Tables 4.13 to 4.15 correspond to the acceptable concentration of naphthalene and other non-carcinogenic PAHs in diesel fuel (refer Section 4.8.3).

If individual PAH concentrations are measured or TPH is not expected to be the limiting consideration for remediation, then use of a TPH surrogate is not necessary, and the route-specific Tier 1 acceptance criteria presented in Tables 4.16 to 4.19 may be used to assess potential health risk.

If the measured heavy-fraction TPH has not resulted from a diesel release (e.g. release from a waste oil tank), the Tier 1 acceptance criteria for TPH, based on criteria for PAHs (i.e. using TPH as a surrogate), are not applicable and PAH concentrations should be measured directly.

Step 4 - Selection of TPH Surrogate Concentration

Table 4.22 presents the calculated TPH acceptance criteria where TPH is to be used as a surrogate for PAHs, for all land uses and soil depths. The TPH fraction C_{10}-C_{14} is used as a surrogate for naphthalene, and the TPH fraction C_{15}-C_{36} is used as a surrogate for pyrene and heavier PAHs. These are based on the Tier 1 acceptance criteria for naphthalene and pyrene in Tables 4.10 to 4.12. All pathways have been considered in the derivation of Table 4.22..

[7] It may be argued that the criteria for the remaining complete exposure pathways should be combined in such a way as to reflect the risk resulting from exposure via the combined pathways. In practice, rarely are more than one or two exposure pathways significant contributors to the overall risk and hence use of the lowest route-specific criteria is unlikely to significantly underestimate the risk.

If the selected surrogate TPH criteria has been derived from a pathway that is not relevant to the specific site (note the superscripts indicate the limiting pathway), then consideration should be given to deriving a revised Tier 1 TPH criterion (refer Step 5). Otherwise, the TPH surrogate is accepted as another limiting criteria (go to Step 6).

Step 5 - Selection of a Revised TPH Criterion as a Surrogate for PAH in Diesel Fuel

In response to Step 2 (Review of Exposure Pathways) revised Tier 1 acceptance criteria may be nominated for PAHs. Given that the Tier 1 acceptance criteria for TPH are based on the PAH criteria, any change in the relevant exposure pathways, should be reflected in revised criteria for TPH.

Naphthalene and pyrene Tier 1 acceptance criteria may be revised using Step 2 of this procedure. The revised PAH acceptance criteria are then used to calculate the TPH surrogate acceptance criteria using the example calculation presented in Table 4.21.

Step 6 - Selecting Revised Tier 1 Acceptance Criteria

For BTEX, PAHs and TPHs the limiting acceptance criteria (lowest) based on the considerations outlined above is defined as the revised Tier 1 acceptance criteria. For TPH criteria this includes the surrogates for the protection from PAHs in diesel (only if applicable).

Step 7 - Comparison of Revised Tier 1 with Measured Contaminant Concentrations

The revised Tier 1 acceptance criteria may be compared with contaminant concentrations on site in soil. If the contaminant concentrations in the soil on site are below the revised Tier 1 acceptance criteria, then no further work is required on a human health risk basis. However, further consideration should be given to aesthetic impacts and to groundwater protection (refer Step 8).

If the measured contaminant concentrations exceed the Tier 1 acceptable criteria, then the available options include:

- consideration of a Tier 2 analysis; or
- remediation of the site to Tier 1 acceptable concentrations.

The cost-benefit considerations for this decision are discussed in Module 1.

Step 8 - Protection of Groundwater Quality

Table 4.20 presents Tier 1 soil screening criteria protective of groundwater quality for:

- a range of soil types
- various combinations of the depth to the contaminated soil layer and groundwater
- potable water quality.

The Tier 1 soil screening criteria for protection of groundwater quality are only an indication of the possible impact of soil contamination acting as a source for groundwater contamination.

If the measured soil concentrations exceed the Tier 1 soil screening criteria for the protection of groundwater quality, then a Tier 2 assessment may be warranted, depending on the results of any groundwater monitoring undertaken as part of the Tier 1 assessment.

Figure 4.2 Flow chart for determining Tier 1 soil acceptance criteria

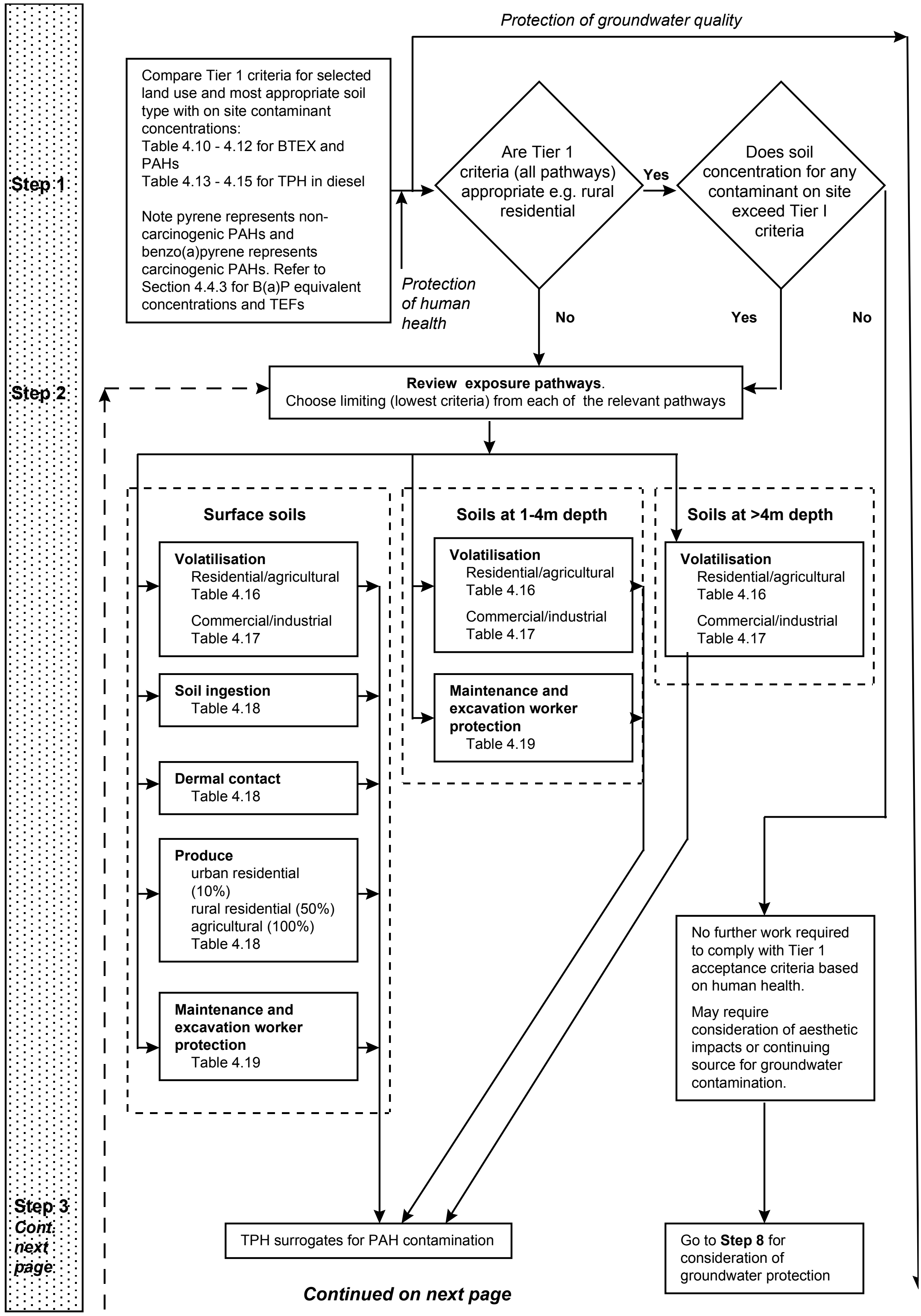


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Figure 4.2 (continued) Flow chart for determining Tier 1 soil acceptance criteria

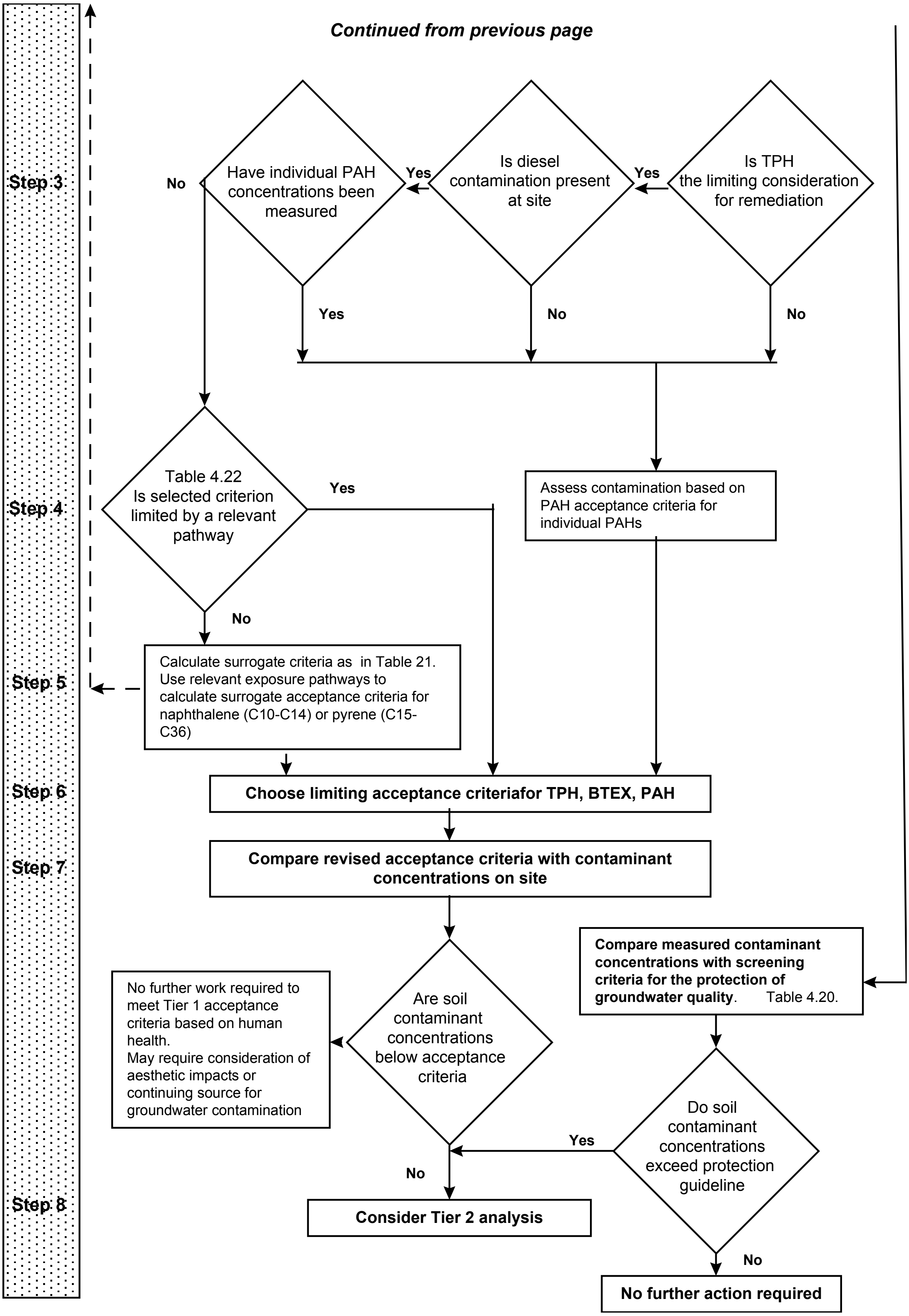

Table 4.10 Tier 1 Soil acceptance criteria *Residential use*[1,3,6] ALL PATHWAYS (all values in mg/kg)

Soil Type/ Contaminant	Depth of contamination		
	Surface (<1 m)	1m - 4 m	> 4 m
SAND			
MAHs			
Benzene	1.1 (v)	1.9 (7,v)	2.4 (7,v)
Toluene	(68) (4,v)	(94) (4,m)	(230) (4,v)
Ethylbenzene	(53) (4,v)	(92) (4,7,v)	(120) (4,v)
Xylenes	(48) (4,v)	(130) (4,7,v)	(180) (4,v)
PAHs			
Naphthalene	58 (v)	70 (v)	80 (v)
Non-carc. (Pyrene)	(1,600) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.27 (p)	(25) (4,m)	NA (2)
SANDY SILT			
MAHs			
Benzene	1.1 (v)	1.9 (v)	2.4 (v)
Toluene	(82) (4,v)	(170) (4,v)	(240) (4,v)
Ethylbenzene	(59) (4,v)	(92) (4,v)	(140) (4,v)
Xylenes	(59) (4,v)	(130) (4,v)	(180) (4,v)
PAHs			
Naphthalene	63 (v)	83 (v)	(130) (4,v)
Non-carc. (Pyrene)	(1,600) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.27 (p)	(25) (4,m)	NA (2)
SILTY CLAY			
MAHs			
Benzene	1.7 (v)	4.6 (v)	12 (v)
Toluene	(210) (4,v)	(950) (4,v)	(3,000) (4,v)
Ethylbenzene	(110) (4,v)	(800) (4,v)	(2,800) (4,v)
Xylenes	(160) (4,v)	(710) (4,v)	(2,200) (4,v)
PAHs			
Naphthalene	69 (v)	(330) (4,v)	(1,100) (4,v)
Non-carc. (Pyrene)	(1,600) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.27 (p)	(25) (4,m)	NA (2)

NOTES:

1. Based on protection of human health. Refer to Table 4.20 for protection of groundwater. Site-specific consideration of aesthetic and ecological impacts is required.
2. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site.
3. Surface soil acceptance criteria are based on the lower value of volatilisation criteria (Table 4.16), other pathway criteria (Table 4.18) and criteria for the protection of maintenance workers (Table 4.19). Criteria for soils at 1 m are based on the lower value of those arising from volatilisation and maintenance criteria. Criteria for soils at 4 m are based on volatilisation only.
4. Brackets denote values exceed threshold likely to correspond to formation of residual separate phase hydrocarbons. For further explanation refer to Appendix 4M.
5. Risk associated with mixture of carcinogenic PAHs assessed by comparison with criteria based on benzo(a)pyrene equivalent concentration. Refer to Section 4.4.3 for details of the calculation of Benzo(a)pyrene equivalent concentrations.
6. The following notes indicate the limiting pathway for each criterion: v - Volatilisation, s - Soil Ingestion, d - Dermal, p - Produce, m - Maintenance/Excavation
7. Due to the nature of boundary conditions in volatilisation model, calculated criteria for sandy soils are higher than that for silt soil type. Therefore, the criteria for sand are set equal to the criteria for silt. Refer Appendix 4D for details.

Table 4.10 (CONTINUED)
Tier 1 Soil acceptance criteria *Residential use*[1,3,6] ALL PATHWAYS
(all values in mg/kg)

Soil Type/ Contaminant	Depth of contamination		
	Surface (<1m)	**1m - 4m**	**> 4m**
CLAY			
MAHs			
Benzene	2.7 (v)	8.8 (v)	(26) (4,v)
Toluene	(320) (4,v)	(2,400) (4,v)	(8,500) (4,v)
Ethylbenzene	(160) (4,v)	NA (2)	NA (2)
Xylenes	(250) (4,v)	(1,800) (4,v)	(6,500) (4,v)
PAHs			
Naphthalene	71 (v)	(360) (4,v)	(1,200) (4,v)
Non-carc. (Pyrene)	(1,600) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.27 (p)	(25) (4,m)	NA (2)
PUMICE			
MAHs			
Benzene	1.2 (v)	2.4 (v)	3.1 (v)
Toluene	(73) (4,v)	(240) (4,v)	(350) (4,v)
Ethylbenzene	(48) (4,v)	(140) (4,v)	(220) (4,v)
Xylenes	(53) (4,v)	(180) (4,v)	(260) (4,v)
PAHs			
Naphthalene	49 (v)	140 (v)	(220) (4,v)
Non-carc. (Pyrene)	(1,600) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.27 (p)	(25) (4,m)	NA (2)
PEATS AND HIGHLY ORGANIC SOILS			
MAHs			
Benzene	5.7 (v)	10 (v)	13 (v)
Toluene	(2,500) (4,v)	(2,900) (4,v)	(3,800) (4,v)
Ethylbenzene	(2,200) (4,v)	(2,500) (4,v)	(3,200) (4,v)
Xylenes	(1,700) (4,v)	(2,000) (4,v)	(2,600) (4,v)
PAHs			
Naphthalene	72 (p)	(2,700) (4,v)	(3,500) (4,v)
Non-carc. (Pyrene)	(1,600) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.27 (p)	(25) (4,m)	NA (2)

NOTES:

1. Based on protection of human health. Refer to Table 4.20 for protection of groundwater. Site-specific consideration of aesthetic and ecological impacts is required.
2. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site.
3. Surface soil acceptance criteria are based on the lower value of volatilisation criteria (Table 4.16), other pathway criteria (Table 4.18) and criteria for the protection of maintenance workers (Table 4.19). Criteria for soils at 1 m are based on the lower value of those arising from volatilisation and maintenance criteria. Criteria for soils at 4 m are based on volatilisation only.
4. Brackets denote values exceed threshold likely to correspond to formation of residual separate phase hydrocarbons. For further explanation refer to Appendix 4M.
5. Risk associated with mixture of carcinogenic PAHs assessed by comparison with criteria based on benzo(a)pyrene equivalent concentration. Refer to Section 4.4.3 for details of the calculation of Benzo(a)pyrene equivalent concentrations.
6. The following notes indicate the limiting pathway for each criterion: v - Volatilisation, s - Soil Ingestion, d - Dermal, p - Produce, m - Maintenance/Excavation

Table 4.11 Tier 1 Soil acceptance criteria *Commercial /Industrial use*[1,3,6] ALL PATHWAYS (all values in mg/kg)

Soil Type/ Contaminant	Depth of contamination		
	Surface (<1m)	1m - 4m	> 4m
SAND			
MAHs			
Benzene	3.0 (m)	3.0 (m)	9.3 (7,v)
Toluene	(94) (4,m)	(94) (4,m)	(770) (4,v)
Ethylbenzene	(180) (4,v)	(300) (4,7,v)	(390) (4,v)
Xylenes	(150) (4,m)	(150) (4,m)	(580) (4,v)
PAHs			
Naphthalene	(190) (4,v)	(230) (4,v)	(260) (4,v)
Non-carc. (Pyrene)	NA (2)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	(11) (4,d)	(25) (4,m)	NA (2)
SANDY SILT			
MAHs			
Benzene	3.6 (v)	7.2 (v)	9.3 (v)
Toluene	(270) (4,v)	(480) (4,m)	(790) (4,v)
Ethylbenzene	(200) (4,v)	(300) (4,v)	(450) (4,v)
Xylenes	(200) (4,v)	(420) (4,v)	(590) (4,v)
PAHs			
Naphthalene	(210) (4,v)	(270) (4,v)	(420) (4,v)
Non-carc. (Pyrene)	NA (2)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	(11) (4,d)	(25) (4,m)	NA (2)
SILTY CLAY			
MAHs			
Benzene	7.2 (v)	(20) (4,v)	(54) (4,v)
Toluene	(670) (4,v)	(3,100) (4,v)	(10,000) (4,v)
Ethylbenzene	(350) (4,v)	(2,600) (4,v)	(9,100) (4,v)
Xylenes	(510) (4,v)	(2,300) (4,v)	(7,300) (4,v)
PAHs			
Naphthalene	(230) (4,v)	(1,100) (4,v)	(3,500) (4,v)
Non-carc. (Pyrene)	NA (2)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	(11) (4,d)	(25) (4,m)	NA (2)

NOTES:

1. Based on protection of human health. Refer to Table 4.20 for protection of groundwater. Site-specific consideration of aesthetic and ecological impacts is required.
2. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site.
3. Surface soil acceptance criteria are based on the lower value of volatilisation criteria (Table 4.16), other pathway criteria (Table 4.18) and criteria for the protection of maintenance workers (Table 4.19). Criteria for soils at 1 m are based on the lower value of those arising from volatilisation and maintenance criteria. Criteria for soils at 4 m are based on volatilisation only.
4. Brackets denote values exceed threshold likely to correspond to formation of residual separate phase hydrocarbons. For further explanation refer to Appendix 4M.
5. Risk associated with mixture of carcinogenic PAHs assessed by comparison with criteria based on benzo(a)pyrene equivalent concentration. Refer to Section 4.4.3 for details of the calculation of Benzo(a)pyrene equivalent concentrations.
6. The following notes indicate the limiting pathway for each criterion: v - Volatilisation, s - Soil Ingestion, d - Dermal, p - Produce, m - Maintenance/Excavation
7. Due to the nature of boundary conditions in volatilisation model, calculated criteria for sandy soils are higher than that for silt soil type. Therefore, the criteria for sand are set equal to the criteria for silt. Refer Appendix 4D for details.

Table 4.11 (CONTINUED)
Tier 1 Soil acceptance criteria *Commercial /Industrial use*[1,3,6] ALL PATHWAYS
(all values in mg/kg)

Soil Type/ Contaminant	Depth of contamination		
	Surface (<1m)	**1m - 4m**	**> 4m**
CLAY			
MAHs			
Benzene	11 (v)	(41) (4,v)	(120) (4,v)
Toluene	(1,000) (4,v)	(7,900) (4,v)	NA (2)
Ethylbenzene	(540) (4,v)	NA (2)	NA (2)
Xylenes	(810) (4,v)	(6,000) (4,v)	NA (2)
PAHs			
Naphthalene	(230) (4,v)	(1,200) (4,v)	(3,800) (4,v)
Non-carc. (Pyrene)	NA (2)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	(11) (4,d)	(25) (4,m)	NA (2)
PUMICE			
MAHs			
Benzene	4.0 (v)	9.0 (v)	12 (v)
Toluene	(250) (4,v)	(780) (4,v)	(1,100) (4,v)
Ethylbenzene	(170) (4,v)	(470) (4,v)	(710) (4,v)
Xylenes	(180) (4,v)	(580) (4,v)	(850) (4,v)
PAHs			
Naphthalene	170 (v)	(450) (4,v)	(710) (4,v)
Non-carc. (Pyrene)	NA (2)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	(11) (4,d)	(25) (4,m)	NA (2)
PEATS AND HIGHLY ORGANIC SOILS			
MAHs			
Benzene	28 (v)	(44) (4,v)	(55) (4,v)
Toluene	(7,500) (4,m)	(7,500) (4,m)	NA (2)
Ethylbenzene	(7,200) (4,v)	(8,100) (4,v)	(10,000) (4,v)
Xylenes	(5,700) (4,v)	(6,600) (4,v)	(8,500) (4,v)
PAHs			
Naphthalene	(8,000) (4,v)	(9,000) (4,v)	NA (2)
Non-carc. (Pyrene)	NA (2)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	(11) (4,d)	(25) (4,m)	NA (2)

NOTES:

1. Based on protection of human health. Refer to Table 4.20 for protection of groundwater. Site-specific consideration of aesthetic and ecological impacts is required.
2. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site.
3. Surface soil acceptance criteria are based on the lower value of volatilisation criteria (Table 4.16), other pathway criteria (Table 4.18) and criteria for the protection of maintenance workers (Table 4.19). Criteria for soils at 1 m are based on the lower value of those arising from volatilisation and maintenance criteria. Criteria for soils at 4 m are based on volatilisation only.
4. Brackets denote values exceed threshold likely to correspond to formation of residual separate phase hydrocarbons. For further explanation refer to Appendix 4M.
5. Risk associated with mixture of carcinogenic PAHs assessed by comparison with criteria based on benzo(a)pyrene equivalent concentration. Refer to Section 4.4.3 for details of the calculation of Benzo(a)pyrene equivalent concentrations.
6. The following notes indicate the limiting pathway for each criterion: v - Volatilisation, s - Soil Ingestion, d - Dermal, p - Produce, m - Maintenance/Excavation

Table 4.12 Tier 1 soil acceptance criteria *Agricultural use* (1,3,6) ALL PATHWAYS (all values mg/kg)

Soil Type/ Contaminant	Depth of contamination		
	Surface (<1m)	1m - 4m	> 4m
SAND			
MAHs			
Benzene	1.1 (v)	1.9 (7,v)	2.4 (7,v)
Toluene	(68) (4,v)	(94) (4,m)	(230) (4,v)
Ethylbenzene	(53) (4,v)	(92) (4,7,v)	(120) (4,v)
Xylenes	(48) (4,v)	(130) (4,7,v)	(180) (4,v)
PAHs			
Naphthalene	7.2 (p)	70 (v)	80 (v)
Non-carc. (Pyrene)	(160) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.027 (p)	(25) (4,m)	NA (2)
SANDY SILT			
MAHs			
Benzene	1.1 (v)	1.9 (v)	2.4 (v)
Toluene	(82) (4,v)	(170) (4,v)	(240) (4,v)
Ethylbenzene	(59) (4,v)	(92) (4,v)	(140) (4,v)
Xylenes	(59) (4,v)	(130) (4,v)	(180) (4,v)
PAHs			
Naphthalene	7.2 (p)	83 (v)	(130) (4,v)
Non-carc. (Pyrene)	(160) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.027 (p)	(25) (4,m)	NA (2)
SILTY CLAY			
MAHs			
Benzene	1.7 (v)	4.6 (v)	12 (v)
Toluene	(210) (4,v)	(950) (4,v)	(3,000) (4,v)
Ethylbenzene	(110) (4,v)	(800) (4,v)	(2,800) (4,v)
Xylenes	(160) (4,v)	(710) (4,v)	(2,200) (4,v)
PAHs			
Naphthalene	7.2 (p)	(330) (4,v)	(1,100) (4,v)
Non-carc. (Pyrene)	(160) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.027 (p)	(25) (4,m)	NA (2)

NOTES:

1. Based on protection of human health. Refer to Table 4.20 for protection of groundwater. Site-specific consideration of aesthetic and ecological impacts is required.
2. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site.
3. Surface soil acceptance criteria are based on the lower value of volatilisation criteria (Table 4.16), other pathway criteria (Table 4.18) and criteria for the protection of maintenance workers (Table 4.19). Criteria for soils at 1 m are based on the lower value of those arising from volatilisation and maintenance criteria. Criteria for soils at 4 m are based on volatilisation only.
4. Brackets denote values exceed threshold likely to correspond to formation of residual separate phase hydrocarbons. For further explanation refer to Appendix 4M.
5. Risk associated with mixture of carcinogenic PAHs assessed by comparison with criteria based on benzo(a)pyrene equivalent concentration. Refer to Section 4.4.3 for details of the calculation of Benzo(a)pyrene equivalent concentrations.
6. The following notes indicate the limiting pathway for each criterion: v - Volatilisation, s - Soil Ingestion, d - Dermal, p - Produce, m - Maintenance/Excavation
7. Due to the nature of boundary conditions in volatilisation model, calculated criteria for sandy soils are higher than that for silt soil type. Therefore, the criteria for sand are set equal to the criteria for silt. Refer Appendix 4D for details.

Table 4.12 (CONTINUED)
Tier 1 soil acceptance criteria *Agricultural use* [1,3,6] ALL PATHWAYS (all values mg/kg)

Soil Type/ Contaminant	Depth of contamination		
	Surface (<1m)	1m - 4m	> 4m
CLAY			
MAHs			
Benzene	2.7 (v)	8.8 (v)	(26) (4,v)
Toluene	(320) (4,v)	(2,400) (4,v)	(8,500) (4,v)
Ethylbenzene	(160) (4,v)	NA (2)	NA (2)
Xylenes	(250) (4,v)	(1,800) (4,v)	(6,500) (4,v)
PAHs			
Naphthalene	7.2 (p)	(360) (4,v)	(1,200) (4,v)
Non-carc. (Pyrene)	(160) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.027 (p)	(25) (4,m)	NA (2)
PUMICE			
MAHs			
Benzene	1.2 (v)	2.4 (v)	3.1 (v)
Toluene	(73) (4,v)	(240) (4,v)	(350) (4,v)
Ethylbenzene	(48) (4,v)	(140) (4,v)	(220) (4,v)
Xylenes	(53) (4,v)	(180) (4,v)	(260) (4,v)
PAHs			
Naphthalene	7.2 (p)	140 (v)	(220) (4,v)
Non-carc. (Pyrene)	(160) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.027 (p)	(25) (4,m)	NA (2)
PEATS AND HIGHLY ORGANIC SOILS			
MAHs			
Benzene	5.7 (v)	10 (v)	13 (v)
Toluene	(2,500) (4,v)	(2,900) (4,v)	(3,800) (4,v)
Ethylbenzene	(2,200) (4,v)	(2,500) (4,v)	(3,200) (4,v)
Xylenes	(1,700) (4,v)	(2,000) (4,v)	(2,600) (4,v)
PAHs			
Naphthalene	7.2 (p)	(2,700) (4,v)	(3,500) (4,v)
Non-carc. (Pyrene)	(160) (4,p)	NA (2)	NA (2)
Benzo(a)pyrene eq. (5)	0.027 (p)	(25) (4,m)	NA (2)

NOTES:

1. Based on protection of human health. Refer to Table 4.20 for protection of groundwater. Site-specific consideration of aesthetic and ecological impacts is required.
2. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site.
3. Surface soil acceptance criteria are based on the lower value of volatilisation criteria (Table 4.16), other pathway criteria (Table 4.18) and criteria for the protection of maintenance workers (Table 4.19). Criteria for soils at 1 m are based on the lower value of those arising from volatilisation and maintenance criteria. Criteria for soils at 4 m are based on volatilisation only.
4. Brackets denote values exceed threshold likely to correspond to formation of residual separate phase hydrocarbons. For further explanation refer to Appendix 4M.
5. Risk associated with mixture of carcinogenic PAHs assessed by comparison with criteria based on benzo(a)pyrene equivalent concentration. Refer to Section 4.4.3 for details of the calculation of Benzo(a)pyrene equivalent concentrations.
6. The following notes indicate the limiting pathway for each criterion: v - Volatilisation, s - Soil Ingestion, d - Dermal, p - Produce, m - Maintenance/Excavation

Table 4.13 Tier 1 soil acceptance criteria for TPH[1.3.5.6] *Residential use* ALL PATHWAYS (all values in mg/kg)

Soil Type/ Contaminant	Depth of contamination		
	Surface (<1m)	**1m - 4m**	**> 4m**
SAND			
C_7-C_9 [4]	120 [m]	120 [m]	(3,800) [7,8,v]
C_{10}-C_{14}	(470) [7,x]	(560) [7,x]	(650) [7,x]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]
SANDY SILT			
C_7-C_9 [4]	(500) [7,m]	(500) [7,m]	(3,800) [7,v]
C_{10}-C_{14}	(510) [7,x]	(670) [7,x]	(1,000) [7,x]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]
SILTY CLAY			
C_7-C_9 [4]	(2,700) [7,v]	(7,300) [7,v]	(19,000) [7,v]
C_{10}-C_{14}	(560) [7,x]	(2,700) [7,x]	(8,900) [7,x]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]
CLAY			
C_7-C_9 [4]	(15,000) [7,v]	NA [2]	NA [2]
C_{10}-C_{14}	(570) [7,x]	(2,900) [7,x]	(9,700) [7,x]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]
PUMICE			
C_7-C_9 [4]	(810) [7,m]	(810) [7,m]	NA [2]
C_{10}-C_{14}	(400) [7,x]	(1,100) [7,x]	(1,800) [7,x]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]
PEATS AND HIGHLY ORGANIC SOILS			
C_7-C_9 [4]	(6,700) [7,m]	(6,700) [7,m]	NA [2]
C_{10}-C_{14}	(580) [7,x]	NA [2]	NA [2]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]

NOTES:

1. Criteria for C10 - C14 and C15 - C36 are based on consideration of aliphatic component of TPH measurement and consideration of TPH as a surrogate measure for PAH, consideration of PAHs completed by extrapolation of PAH content of diesel and PAH criteria (refer Table 4.10)
2. NA indicates estimated criterion exceeds 20,000 mg/kg. At 20,000 mg/kg residual separate phase is expected to have formed in soil matrix. Some aesthetic impact may be noted.
3. Based on protection of human health only. Site specific consideration of aesthetic and ecological impact is required.
4. Based on health effects associated with aliphatic component only. Separate consideration of the health effects associated with the aromatic component (i.e. BTEX) is required.
5. Soil acceptance criteria are based on the lower value of criteria based on volatilisation (Table 4.16), other pathways (Table 4.18), criteria for the protection of maintenance workers (Table 4.19) and TPH criteria developed as surrogates for PAHs (Table 4.22). Surface soils criteria are based on all three pathways, criteria for soils at 1 m are based on volatilisation and maintenance workers, and criteria for soils at 4 m are based on volatilisation only. PAH surrogate considerations apply at all depths.
6. The following notes indicate the limiting pathway for each criterion: v - Volatilisation, s - Soil Ingestion d - Dermal, p - Produce, m - Maintenance/Excavation, x - PAH surrogate
7. Brackets denote values exceed threshold likely to correspond to formation of residual separate phase hydrocarbons. For further explanation refer to Appendix 4M.
8. Due to the nature of boundary conditions in volatilisation model, calculated criteria for sandy soils are higher than that for silt soil type. Therefore, the criteria for sand are set equal to the criteria for silt. Refer Appendix 4D for details.

Table 4.14 Tier 1 soil acceptance criteria for TPH[1.3.5.6] *Commercial/industrial use* ALL PATHWAYS (all values in mg/kg)

Soil Type/ Contaminant	Depth of contamination		
	Surface (<1m)	1m - 4m	> 4m
SAND			
C_7-C_9 [4]	120 [m]	120 [m]	(12,000) [7,8,v]
C_{10}-C_{14}	(1,500) [7,x]	(1,900) [7,x]	(2,100) [7,x]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]
SANDY SILT			
C_7-C_9 [4]	(500) [7,m]	(500) [7,m]	(12,000) [7,v]
C_{10}-C_{14}	(1,700) [7,x]	(2,200) [7,x]	(3,400) [7,x]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]
SILTY CLAY			
C_7-C_9 [4]	(8,800) [7,v]	(20,000) [7,m]	NA [2]
C_{10}-C_{14}	(1,900) [7,x]	(8,900) [7,x]	NA [2]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]
CLAY			
C_7-C_9 [4]	NA [2]	NA [2]	NA [2]
C_{10}-C_{14}	(1,900) [7,x]	(9,700) [7,x]	NA [2]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]
PUMICE			
C_7-C_9 [4]	(810) [7,m]	(810) [7,m]	(16,000) [7,v]
C_{10}-C_{14}	(1,400) [7,x]	(3,600) [7,x]	(5,700) [7,x]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]
PEATS AND HIGHLY ORGANIC SOILS			
C_7-C_9 [4]	(6,700) [7,m]	(6,700) [7,m]	NA [2]
C_{10}-C_{14}	NA [2]	NA [2]	NA [2]
C_{15}-C_{36}	NA [2]	NA [2]	NA [2]

NOTES:

1. Criteria for C10 - C14 and C15 - C36 are based on consideration of aliphatic component of TPH measurement and consideration of TPH as a surrogate measure for PAH, consideration of PAHs completed by extrapolation of PAH content of diesel and PAH criteria (refer Table 4.10)
2. NA indicates estimated criterion exceeds 20,000 mg/kg. At 20,000 mg/kg residual separate phase is expected to have formed in soil matrix. Some aesthetic impact may be noted.
3. Based on protection of human health only. Site specific consideration of aesthetic and ecological impact is required.
4. Based on health effects associated with aliphatic component only. Separate consideration of the health effects associated with the aromatic component (i.e. BTEX) is required.
5. Soil acceptance criteria are based on the lower value of criteria based on volatilisation (Table 4.16), other pathways (Table 4.18), criteria for the protection of maintenance workers (Table 4.19) and TPH criteria developed as surrogates for PAHs (Table 4.22). Surface soils criteria are based on all three pathways, criteria for soils at 1 m are based on volatilisation and maintenance workers, and criteria for soils at 4 m are based on volatilisation only. PAH surrogate considerations apply at all depths.
6. The following notes indicate the limiting pathway for each criterion: v - Volatilisation, s - Soil Ingestion d - Dermal, p - Produce, m - Maintenance/Excavation, x - PAH surrogate
7. Brackets denote values exceed threshold likely to correspond to formation of residual separate phase hydrocarbons. For further explanation refer to Appendix 4MAppendix 4M.
8. Due to the nature of boundary conditions in volatilisation model, calculated criteria for sandy soils are higher than that for silt soil type. Therefore, the criteria for sand are set equal to the criteria for silt. Refer Appendix 4D for details.

Table 4.15 Tier 1 soil acceptance criteria for TPH[1.3.5.6] *Agricultural use* ALL PATHWAYS

(all values in mg/kg)

Soil Type/ Contaminant	Depth of contamination		
	Surface (<1m)	**1m - 4m**	**> 4m**
SAND			
C_7-C_9 (4)	120 (m)	120 (m)	(3,800) (7,8,v)
C_{10}-C_{14}	58 (x)	(560) (7,x)	(650) (7,x)
C_{15}-C_{36}	(4,000) (7,x)	NA (2)	NA (2)
SANDY SILT			
C_7-C_9 (4)	(500) (7,m)	(500) (7,m)	(3,800) (7,v)
C_{10}-C_{14}	58 (x)	(670) (7,x)	(4,900) (7,v)
C_{15}-C_{36}	(4,000) (7,x)	NA (2)	NA (2)
SILTY CLAY			
C_7-C_9 (4)	(2,700) (7,v)	(7,300) (7,v)	(19,000) (7,v)
C_{10}-C_{14}	58 (x)	(2,700) (7,x)	(8,900) (7,x)
C_{15}-C_{36}	(4,000) (7,x)	NA (2)	NA (2)
CLAY			
C_7-C_9 (4)	(15,000) (7,v)	NA (2)	NA (2)
C_{10}-C_{14}	58 (x)	(2,900) (7,x)	(9,700) (7,x)
C_{15}-C_{36}	(4,000) (7,x)	NA (2)	NA (2)
PUMICE			
C_7-C_9 (4)	(810) (7,m)	(810) (7,m)	(4,800) (7,v)
C_{10}-C_{14}	58 (x)	(1,100) (7,x)	(1,800) (7,x)
C_{15}-C_{36}	(4,000) (7,x)	NA (2)	NA (2)
PEATS AND HIGHLY ORGANIC SOILS			
C_7-C_9 (4)	(6,700) (7,m)	(6,700) (7,m)	NA (2)
C_{10}-C_{14}	58 (x)	NA (2)	NA (2)
C_{15}-C_{36}	(4,000) (7,x)	NA (2)	NA (2)

NOTES:

1. Criteria for C10 - C14 and C15 - C36 are based on consideration of aliphatic component of TPH measurement and consideration of TPH as a surrogate measure for PAH, consideration of PAHs completed by extrapolation of PAH content of diesel and PAH criteria (refer Table 4.10)
2. NA indicates estimated criterion exceeds 20,000 mg/kg. At 20,000 mg/kg residual separate phase is expected to have formed in soil matrix. Some aesthetic impact may be noted.
3. Based on protection of human health only. Site specific consideration of aesthetic and ecological impact is required.
4. Based on health effects associated with aliphatic component only. Separate consideration of the health effects associated with the aromatic component (i.e. BTEX) is required.
5. Soil acceptance criteria are based on the lower value of criteria based on volatilisation (Table 4.16), other pathways (Table 4.18), criteria for the protection of maintenance workers (Table 4.19) and TPH criteria developed as surrogates for PAHs (Table 4.22). Surface soils criteria are based on all three pathways, criteria for soils at 1 m are based on volatilisation and maintenance workers, and criteria for soils at 4 m are based on volatilisation only. PAH surrogate considerations apply at all depths.
6. The following notes indicate the limiting pathway for each criterion: v - Volatilisation, s - Soil Ingestion d - Dermal, p - Produce, m - Maintenance/Excavation, x - PAH surrogate
7. Brackets denote values exceed threshold likely to correspond to formation of residual separate phase hydrocarbons. For further explanation refer to Appendix 4M.
8. Due to the nature of boundary conditions in volatilisation model, calculated criteria for sandy soils are higher than that for silt soil type. Therefore, the criteria for sand are set equal to the criteria for silt. Refer Appendix 4D for details.

Table 4.16 Route specific soil acceptance criteria through INHALATION pathway
Residential/agricultural use
(all values in mg/kg)

Soil Type/ Contaminant	Depth of Contamination [2] Surface (<1 m) Indoor	Outdoor	1 m - 4 m Indoor	Outdoor	> 4 m Indoor	Outdoor
SAND						
TPHs						
C_7-C_9	1,600	NA [1]	4,000	NA [1]	4,400	NA [1]
C_{10}-C_{14}	2,100	20,000	2,900	NA [1]	3,300	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	1.1	160	2.4	180	2.6	200
Toluene	68	5,200	210	6,900	230	10,000
Ethylbenzene	53	1,400	100	2,300	120	4,300
Xylenes	48	4,300	160	5,600	180	8,100
PAHs						
Naphthalene	58	380	70	850	80	2,300
Non-carc. (Pyrene)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene eq.	NA [1]	530	NA [1]	NA [1]	NA [1]	NA [1]
SANDY SILT						
TPHs						
C_7-C_9	1,600	NA [1]	3,000	NA [1]	3,800	NA [1]
C_{10}-C_{14}	2,400	NA [1]	3,200	NA [1]	4,900	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	1.1	170	1.9	200	2.4	270
Toluene	82	5,200	170	10,000	240	NA [1]
Ethylbenzene	59	2,100	92	4,500	140	NA [1]
Xylenes	59	4,300	130	8,100	180	NA [1]
PAHs						
Naphthalene	63	820	83	3,000	130	9,800
Non-carc. (Pyrene)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene eq.	NA [1]	290	NA [1]	NA [1]	NA [1]	NA [1]
SILTY CLAY						
TPHs						
C_7-C_9	2,700	NA [1]	7,300	NA [1]	19,000	NA [1]
C_{10}-C_{14}	3,200	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	1.7	300	4.6	660	12	1,700
Toluene	210	NA [1]	950	NA [1]	3,000	NA [1]
Ethylbenzene	110	NA [1]	800	NA [1]	2,800	NA [1]
Xylenes	160	NA [1]	710	NA [1]	2,200	NA [1]
PAHs						
Naphthalene	69	3,400	330	NA [1]	1,100	NA [1]
Non-carc. (Pyrene)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene eq.	NA [1]	150	NA [1]	NA [1]	NA [1]	NA [1]

NOTE:

1. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site (i.e. 20,000 mg/kg for TPH, 10,000 mg/kg for other contaminants).
2. Assumes a 2 m thick layer of contaminated soil extending down from the depth indicated.

Table 4.16 (CONTINUED)

Route specific soil acceptance criteria through INHALATION pathway
***Residential/agricultural use* (all values in mg/kg)**

Soil Type/ Contaminant	Depth of Contamination (2)					
	Surface (<1m)		1m - 4m		> 4m	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
CLAY						
TPHs						
C_7-C_9	15,000	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
C_{10}-C_{14}	11,000	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
C_{15}-C_{36}	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
MAHs						
Benzene	2.7	480	8.8	1,300	26	3,900
Toluene	320	NA (1)	2,400	NA (1)	8,500	NA (1)
Ethylbenzene	160	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
Xylenes	250	NA (1)	1,800	NA (1)	6,500	NA (1)
PAHs						
Naphthalene	71	3,600	360	NA (1)	1,200	NA (1)
Non-carc. (Pyrene)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
Benzo(a)pyrene eq.	NA (1)	130	NA (1)	NA (1)	NA (1)	NA (1)
PUMICE						
TPHs						
C_7-C_9	1,800	NA (1)	3,700	NA (1)	4,800	NA (1)
C_{10}-C_{14}	1,500	NA (1)	5,300	NA (1)	8,200	NA (1)
C_{15}-C_{36}	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
MAHs						
Benzene	1.2	180	2.4	230	3.1	330
Toluene	73	6,500	240	NA (1)	350	NA (1)
Ethylbenzene	48	3,000	140	6,600	220	NA (1)
Xylenes	53	5,000	180	10,000	260	NA (1)
PAHs						
Naphthalene	49	1,100	140	4,900	220	NA (1)
Non-carc. (Pyrene)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
Benzo(a)pyrene eq.	NA (1)	310	NA (1)	NA (1)	NA (1)	NA (1)
PEATS AND HIGHLY ORGANIC SOILS						
TPHs						
C_7-C_9	12,000	NA (1)	19,000	NA (1)	NA (1)	NA (1)
C_{10}-C_{14}	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
C_{15}-C_{36}	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
MAHs						
Benzene	5.7	200	10	370	13	750
Toluene	2,500	NA (1)	2,900	NA (1)	3,800	NA (1)
Ethylbenzene	2,200	9,700	2,500	NA (1)	3,200	NA (1)
Xylenes	1,700	NA	2,000	NA (1)	2,600	NA (1)
PAHs						
Naphthalene	2,400	3,800	2,700	NA (1)	3,500	NA (1)
Non-carc. (Pyrene)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
Benzo(a)pyrene eq.	NA (1)	2,500	NA (1)	NA (1)	NA (1)	NA (1)

NOTE:

1. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site (i.e. 20,000 mg/kg for TPH, 10,000 mg/kg for other contaminants).
2. Assumes a 2 m thick layer of contaminated soil extending down from the depth indicated.

Table 4.17 Route specific soil acceptance criteria through INHALATION pathway
Commercial use
(all values in mg/kg)

Soil Type/ Contaminant	Depth of Contamination [2]					
	Surface (<1m)		1m - 4m		> 4m	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
SAND						
TPHs						
C_7-C_9	5,200	NA [1]	13,000	NA [1]	15,000	NA [1]
C_{10}-C_{14}	7,000	NA [1]	9,600	NA [1]	11,000	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	3.6	480	8.8	530	9.6	610
Toluene	220	NA [1]	690	NA [1]	770	NA [1]
Ethylbenzene	180	4,000	340	6,700	390	NA [1]
Xylenes	160	NA [1]	520	NA [1]	580	NA [1]
PAHs						
Naphthalene	190	1,100	230	2,500	260	6,700
Non-carc. (Pyrene)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene eq.	NA [1]	1,900	NA [1]	NA [1]	NA [1]	NA [1]
SANDY SILT						
TPHs						
C_7-C_9	5,200	NA [1]	9,800	NA [1]	12,000	NA [1]
C_{10}-C_{14}	7,800	NA [1]	10,000	NA [1]	16,000	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	3.6	480	7.2	610	9.3	860
Toluene	270	NA [1]	550	NA [1]	790	NA [1]
Ethylbenzene	200	6,200	300	NA [1]	450	NA [1]
Xylenes	200	NA [1]	420	NA [1]	590	NA [1]
PAHs						
Naphthalene	210	2,400	270	8,700	420	NA [1]
Non-carc. (Pyrene)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene eq.	NA [1]	1,000	NA [1]	NA [1]	NA [1]	NA [1]
SILTY CLAY						
TPHs						
C_7-C_9	8,800	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{10}-C_{14}	10,000	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	7.2	1,100	20	2,500	54	7,100
Toluene	670	NA [1]	3,100	NA [1]	10,000	NA [1]
Ethylbenzene	350	NA [1]	2,600	NA [1]	9,100	NA [1]
Xylenes	510	NA [1]	2,300	NA [1]	7,300	NA [1]
PAHs						
Naphthalene	230	10,000	1,100	NA [1]	3,500	NA [1]
Non-carc. (Pyrene)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene eq.	NA [1]	530	NA [1]	NA [1]	NA [1]	NA [1]

NOTE:

1. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site (i.e. 20,000 mg/kg for TPH, 10,000 mg/kg for other contaminants).
2. Assumes a 2 m thick layer of contaminated soil extending down from the depth indicated.

Table 4.17 (CONTINUED)
Route specific soil acceptance criteria through INHALATION pathway *Commercial use* (all values in mg/kg)

Soil Type/ Contaminant	Depth of Contamination [2]					
	Surface (<1m)		1m - 4m		> 4m	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
CLAY						
TPHs						
C_7-C_9	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{10}-C_{14}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	11	1,700	41	5,300	120	NA [1]
Toluene	1,000	NA [1]	7,900	NA [1]	NA [1]	NA [1]
Ethylbenzene	540	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Xylenes	810	NA [1]	6,000	NA [1]	NA [1]	NA [1]
PAHs						
Naphthalene	230	10,000	1,200	NA [1]	3,800	NA [1]
Non-carc. (Pyrene)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene eq.	NA [1]	460	NA [1]	NA [1]	NA [1]	NA [1]
PUMICE						
TPHs						
C_7-C_9	5,800	NA [1]	12,000	NA [1]	16,000	NA [1]
C_{10}-C_{14}	5,400	NA [1]	17,000	NA [1]	NA [1]	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	4.0	540	9.0	720	12	1,100
Toluene	250	NA [1]	780	NA [1]	1,100	NA [1]
Ethylbenzene	170	8,600	470	NA [1]	710	NA [1]
Xylenes	180	NA [1]	580	NA [1]	850	NA [1]
PAHs						
Naphthalene	170	3,300	450	NA [1]	710	NA [1]
Non-carc. (Pyrene)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene eq.	NA [1]	1,100	NA [1]	NA [1]	NA [1]	NA [1]
PEATS AND HIGHLY ORGANIC SOILS						
TPHs						
C_7-C_9	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{10}-C_{14}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	28	600	44	1,300	55	2,800
Toluene	8,300	NA [1]	9,600	NA [1]	NA [1]	NA [1]
Ethylbenzene	7,200	NA [1]	8,100	NA [1]	10,000	NA [1]
Xylenes	5,700	NA [1]	6,600	NA [1]	8,500	NA [1]
PAHs						
Naphthalene	8,000	NA [1]	9,000	NA [1]	NA [1]	NA [1]
Non-carc. (Pyrene)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene eq.	NA [1]	8,900	NA [1]	NA [1]	NA [1]	NA [1]

NOTE:

1. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site (i.e. 20,000 mg/kg for TPH, 10,000 mg/kg for other contaminants).
2. Assumes a 2 m thick layer of contaminated soil extending down from the depth indicated.

Table 4.18 Route-specific soil acceptance criteria OTHER PATHWAYS (all values in mg/kg)

Contaminant	Pathway			
	Soil Ingestion	Dermal	Produce Ingestion	
			10% [1]	50% [2]
RESIDENTIAL				
TPHs				
C_7-C_9	NA [5]	NA [5]	- [3]	- [3]
C_{10}-C_{14} [4]	16,000	12,000	-	-
C_{15}-C_{36} [4]	NA [5]	NA [5]	-	-
MAHs				
Benzene	520	190	-	-
Toluene	NA [5]	NA [5]	-	-
Ethylbenzene	NA [5]	NA [5]	-	-
Xylenes	NA [5]	NA [5]	-	-
PAHs				
Naphthalene	630	4,800	72	14
Non-carc. (Pyrene)	4,700	NA [5]	1,600	330
Benzo(a)pyrene eq.	2.1	7.5	0.27	0.052
AGRICULTURAL				
TPHs				
C_7-C_9	NA [5]	NA [5]	- [3]	
C_{10}-C_{14} [4]	16,000	6,000	- [3]	
C_{15}-C_{36} [4]	NA [5]	NA [5]	- [3]	
MAHs				
Benzene	520	95	- [3]	
Toluene	NA [5]	NA [5]	- [3]	
Ethylbenzene	NA [5]	6,000	- [3]	
Xylenes	NA [5]	NA [5]	- [3]	
PAHs				
Naphthalene	630	2,400	7.2	
Non-carc. (Pyrene)	4,700	NA [5]	160	
Benzo(a)pyrene eq.	2.1	3.8	0.027	

NOTE:

1. Refer to Table 4.21 for derivation of heavy fraction TPH.
2. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site.
3. Plant uptake not a complete pathway for commercial and maintenance workers.

Table 4.18 (continued)
Route specific soil acceptance criteria OTHER PATHWAYS (all values in mg/kg)

Contaminant	Pathway		
	Soil Ingestion	Dermal	Produce Ingestion
COMMERCIAL / INDUSTRIAL			
TPHs			
C_7-C_9	NA [2]	NA [2]	- [3]
C_{10}-C_{14} [1]	NA [2]	NA [2]	- [3]
C_{15}-C_{36} [1]	NA [2]	NA [2]	- [3]
MAHs			
Benzene	5,100	270	- [3]
Toluene	NA [2]	NA [2]	- [3]
Ethylbenzene	NA [2]	NA [2]	- [3]
Xylenes	NA [2]	NA [2]	- [3]
PAHs			
Naphthalene	NA [2]	9,100	- [3]
Non-carc. (Pyrene)	NA [2]	NA [2]	- [3]
Benzo(a)pyrene eq.	20	11	- [3]
MAINTENANCE			
TPHs			
C_7-C_9	NA [2]	NA [2]	- [3]
C_{10}-C_{14} [1]	NA [2]	NA [2]	- [3]
C_{15}-C_{36} [1]	NA [2]	NA [2]	- [3]
MAHs			
Benzene	6,200	870	- [3]
Toluene	NA [2]	NA [2]	- [3]
Ethylbenzene	NA [2]	NA [2]	- [3]
Xylenes	NA [2]	NA [2]	- [3]
PAHs			
Naphthalene	NA [2]	NA [2]	- [3]
Non-carc. (Pyrene)	NA [2]	NA [2]	- [3]
Benzo(a)pyrene eq.	25	35	- [3]

NOTE:

1. Refer to Table 4.21 for derivation of heavy fraction TPH
2. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site.
3. Plant uptake not a complete pathway for commercial and maintenance workers

Table 4.19 Tier 1 Soil acceptance criteria *Maintenance/excavation workers* (all values mg/kg)

Soil Type/ Contaminant		Surface Soil (mg/kg)
SAND		
Alkanes		
	C_7-C_9	120
	C_{10}-C_{14}	6,500
	C_{15}-C_{36}	NA [(2)]
MAHs		
	Benzene	3.0
	Toluene	94
	Ethylbenzene	670
	Xylenes	150
PAHs		
	Naphthalene	640
	Non-carc. (Pyrene)	NA [(2)]
	Benzo(a)pyrene eq.	25
SANDY SILT		
Alkanes		
	C_7-C_9	500
	C_{10}-C_{14}	31,000
	C_{15}-C_{36}	NA [(2)]
MAHs		
	Benzene	17
	Toluene	480
	Ethylbenzene	3,200
	Xylenes	780
PAHs		
	Naphthalene	3,100
	Non-carc. (Pyrene)	NA [(2)]
	Benzo(a)pyrene eq.	25

NOTE:

1. Based on protection of human health. Refer to Table 4.20 for protection of groundwater. Site-specific consideration of aesthetic and ecological impacts is required.
2. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site.
3. Criteria based on the lower of criteria for maintenance workers (Appendix 4G Table 4G4) and excavation workers (Appendix K).

Table 4.19 (CONTINUED)
Tier 1 Soil acceptance criteria *Maintenance/Excavation workers* (all values mg/kg)

Soil Type/ Contaminant		Surface Soil (mg/kg)
SILTY CLAY		
Alkanes		
	C_7-C_9	20,000
	C_{10}-C_{14}	NA (2)
	C_{15}-C_{36}	NA (2)
MAHs		
	Benzene	700
	Toluene	NA (2)
	Ethylbenzene	NA (2)
	Xylenes	NA (2)
PAHs		
	Naphthalene	NA (2)
	Non-carc. (Pyrene)	NA (2)
	Benzo(a)pyrene eq.	25
CLAY		
Alkanes		
	C_7-C_9	NA (2)
	C_{10}-C_{14}	NA (2)
	C_{15}-C_{36}	NA (2)
MAHs		
	Benzene	870
	Toluene	NA (2)
	Ethylbenzene	NA (2)
	Xylenes	NA (2)
PAHs		
	Naphthalene	NA (2)
	Non-carc. (Pyrene)	NA (2)
	Benzo(a)pyrene eq.	25

NOTE:

1. Based on protection of human health. Refer to Table 4.20 for protection of groundwater. Site-specific consideration of aesthetic and ecological impacts is required.
2. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site.
3. Criteria based on the lower of criteria for maintenance workers (Appendix G Table G4) and excavation workers (Appendix K).

Table 4.19 (CONTINUED)
Tier 1 Soil acceptance criteria *Maintenance/Excavation workers* (all values mg/kg)

Soil Type/ Contaminant		Surface Soil (mg/kg)
PUMICE		
Alkanes		
	C_7-C_9	810
	C_{10}-C_{14}	NA (2)
	C_{15}-C_{36}	NA (2)
MAHs		
	Benzene	28
	Toluene	820
	Ethylbenzene	5,600
	Xylenes	1,300
PAHs		
	Naphthalene	5,300
	Non-carc. (Pyrene)	NA (2)
	Benzo(a)pyrene eq.	25
PEATS AND HIGHLY ORGANIC SOILS		
Alkanes		
	C_7-C_9	6,700
	C_{10}-C_{14}	NA (2)
	C_{15}-C_{36}	NA (2)
MAHs		
	Benzene	190
	Toluene	7,500
	Ethylbenzene	NA (2)
	Xylenes	NA (2)
PAHs		
	Naphthalene	NA (2)
	Non-carc. (Pyrene)	NA (2)
	Benzo(a)pyrene eq.	25

NOTE:

1. Based on protection of human health. Refer to Table 4.20 for protection of groundwater. Site-specific consideration of aesthetic and ecological impacts is required.
2. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site.
3. Criteria based on the lower of criteria for maintenance workers (Appendix G Table G4) and excavation workers (Appendix K).

Table 4.20 Soil acceptance criteria for PROTECTION OF GROUNDWATER QUALITY (all values in mg/kg)

Soil Type/ Contaminant	Depth of Contamination (3)					
	Surface (<1 m)			1 m - 4 m		> 4 m
	GW 2 m (5)	GW 4 m	GW 8 m	GW 4 m (5)	GW 8 m	GW 8 m
SAND						
TPHs						
C_7-C_9	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
C_{10}-C_{14}	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
C_{15}-C_{36}	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
MAHs						
Benzene	0.17	2.8	9.2	0.78	5.1	1.3
Toluene	(39)	(700)	(6,000)	(200)	(1,300)	(320)
Ethylbenzene	(50)	NA (1)	NA (1)	(280)	NA (1)	(790)
Xylenes	(24)	(410)	(1,400)	(120)	(750)	(190)
PAHs						
Naphthalene	1.9	53	NA (1)	3.7	NA (1)	20
Non-carc. (Pyrene)	(56)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
Benzo(a)pyrene	(40)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
SANDY SILT						
TPHs						
C_7-C_9	(5,200)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
C_{10}-C_{14}	(9,200)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
C_{15}-C_{36}	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
MAHs						
Benzene	0.029	0.46	4.8	0.084	2.0	0.21
Toluene	6.0	(100)	NA (1)	18	(540)	45
Ethylbenzene	7.2	(2,600)	NA (1)	(23)	NA (1)	(170)
Xylenes	3.7	(61)	(1,400)	11	(250)	(27)
PAHs						
Naphthalene	0.28	16	NA (1)	0.62	NA (1)	NA (1)
Non-carc. (Pyrene)	7.9	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
Benzo(a)pyrene	(5.7)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
SILTY CLAY						
TPHs						
C_7-C_9	(710)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
C_{10}-C_{14}	(1,500)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
C_{15}-C_{36}	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
MAHs						
Benzene	0.0057	0.66	NA (1)	0.11	NA (1)	0.34
Toluene	1.1	(8,900)	NA (1)	8.3	NA (1)	(8,800)
Ethylbenzene	1.2	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
Xylenes	0.67	(51)	NA (1)	5.9	NA (1)	(50)
PAHs						
Naphthalene	0.047	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
Non-carc. (Pyrene)	1.3	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)
Benzo(a)pyrene	0.93	NA (1)	NA (1)	NA (1)	NA (1)	NA (1)

NOTE:

1. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site (i.e. 20,000 mg/kg for TPH, 10,000 mg/kg for other contaminants).
2. Based on Tier 1 groundwater acceptance criteria for potable use.
3. Each depth is measured from surface to top of contaminated soil layer or to the groundwater table. Contaminated soil layer assumed to be 2 m thick.
4. Criteria based on assumption of adsorbed phase hydrocarbons only and 1st order biodegradation. Migration of separate phase hydrocarbons through soil profile may result in greater impact than indicated by above criteria.
5. Contaminated soil layer is in direct contact with groundwater and hence no attenuation associated with vertical migration through the soil column occurs.

Table 4.20 (CONTINUED)
Soil acceptance criteria for PROTECTION OF GROUNDWATER QUALITY (all values in mg/kg)

Soil Type/ Contaminant	Depth of Contamination [3]					
	Surface (<1m)			1m - 4m		> 4m
	GW 2m [5]	GW 4m	GW 8m	GW 4m [5]	GW 8m	GW 8m
CLAY						
TPHs						
C_7-C_9	(590)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{10}-C_{14}	(1,400)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	0.0054	(850)	NA [1]	0.75	NA [1]	(830)
Toluene	1.0	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Ethylbenzene	1.1	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Xylenes	0.61	NA [1]	NA [1]	(840)	NA [1]	NA [1]
PAHs						
Naphthalene	0.043	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Non-carc. (Pyrene)	1.2	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene	0.85	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
PUMICE						
TPHs						
C_7-C_9	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{10}-C_{14}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	0.24	2.5	17	0.52	8.1	1.1
Toluene	51	(560)	(10,000)	(120)	(1,600)	(250)
Ethylbenzene	63	(1,800)	NA [1]	(150)	NA [1]	(730)
Xylenes	32	(330)	(2,200)	(70)	(1,100)	(150)
PAHs						
Naphthalene	2.4	60	NA [1]	4.0	NA [1]	NA [1]
Non-carc. (Pyrene)	(70)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene	(50)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
PEATS AND HIGHLY ORGANIC SOILS						
TPHs						
C_7-C_9	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{10}-C_{14}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
C_{15}-C_{36}	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
MAHs						
Benzene	3.7	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Toluene	(1,000)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Ethylbenzene	(1,400)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Xylenes	(630)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
PAHs						
Naphthalene	55	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Non-carc. (Pyrene)	(1,600)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]
Benzo(a)pyrene	(1,200)	NA [1]	NA [1]	NA [1]	NA [1]	NA [1]

NOTE:

1. NA indicates contaminant not limiting as estimated health-based criterion is significantly higher than that likely to be encountered on site (i.e. 20,000 mg/kg for TPH, 10,000 mg/kg for other contaminants).
2. Based on Tier 1 groundwater acceptance criteria for potable use.
3. Each depth is measured from surface to top of contaminated soil layer or to the groundwater table. Contaminated soil layer assumed to be 2m thick.
4. Criteria based on assumption of adsorbed phase hydrocarbons only and 1st order biodegradation. Migration of separate phase hydrocarbons through soil profile may result in greater impact than indicated by above criteria.
5. Contaminated soil layer is in direct contact with groundwater and hence no attenuation associated with vertical migration through the soil column occurs.

Table 4.21 Soil screening criteria for heavy fraction TPH associated with diesel - Sample calculation sand soil type/surface soils[1]

Contaminant	Surrogate TPH range	Polycyclic Aromatic Hydrocarbons: Concentration of PAH species in diesel (%w/w)	Polycyclic Aromatic Hydrocarbons: Tier 1 Acceptance criteria (mg/kg)	Safety factor	TPH screening criteria (mg/kg)
RESIDENTIAL					
C_{10}-C_{14}	naphthalene	3.1	58	4	470 [2]
C_{15}-C_{36}	pyrene	0.4	1,600	10	> 20,000
COMMERCIAL / INDUSTRIAL					
C_{10}-C_{14}	naphthalene	3.1	190	4	1,500
C_{15}-C_{36}	pyrene	0.4	NA	10	> 20,000
AGRICULTURAL					
C_{10}-C_{14}	naphthalene	3.1	7.2	4	58
C_{15}-C_{36}	pyrene	0.4	160	10	4,000

NOTE:

1. Calculations applicable to all soil types and depths. Results of calculations are presented in Table 4.22
2. Criteria calculates as: 58 / (0.031 * 4) = 470

Table 4.22 Soil screening criteria for heavy fraction TPH associated with diesel *Residential use* (all values mg/kg)

Contaminant	Depth of contamination: Surface (<1 m)	Depth of contamination: 1 m - 4 m	Depth of contamination: > 4 m
SAND			
C_{10}-C_{14}	470 (v)	560 (v)	650 (v)
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000
SANDY SILT			
C_{10}-C_{14}	510 (v)	670 (v)	1,000 (v)
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000
SILTY CLAY			
C_{10}-C_{14}	560 (v)	2,700 (v)	8,900 (v)
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000
CLAY			
C_{10}-C_{14}	570 (v)	2,900 (v)	9,700 (v)
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000
PUMICE			
C_{10}-C_{14}	400 (v)	1,100 (v)	1,800 (v)
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000
PEATS AND HIGHLY ORGANIC SOILS			
C_{10}-C_{14}	580 (p)	> 20,000	> 20,000
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000

NOTES:

1. Sample calculation presented in Table 4.21.
2. Surrogate criteria based on PAH criteria presented in Table 4.10.
3. The following indicators denote the limiting pathway for each criterion: v - Volatilisation, p - Produce

Table 4.22 (CONTINUED)
Soil screening criteria for heavy fraction TPH associated with diesel *Commercial / industrial use* (all values mg/kg)

Soil Type/ Contaminant	Depth of contamination		
	Surface (<1m)	1m - 4m	> 4m
SAND			
C_{10}-C_{14}	1,500 (v)	1,900 (v)	2,100 (v)
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000
SANDY SILT			
C_{10}-C_{14}	1,700 (v)	2,200 (v)	3,400 (v)
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000
SILTY CLAY			
C_{10}-C_{14}	1,900 (v)	8,900 (v)	> 20,000
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000
CLAY			
C_{10}-C_{14}	1,900 (v)	9,700 (v)	> 20,000
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000
PUMICE			
C_{10}-C_{14}	1,400 (v)	3,600 (v)	5,700 (v)
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000
PEATS AND HIGHLY ORGANIC SOILS			
C_{10}-C_{14}	> 20,000	> 20,000	> 20,000
C_{15}-C_{36}	> 20,000	> 20,000	> 20,000

Table 4.22 (CONTINUED)
Soil screening criteria for heavy fraction TPH associated with diesel *Agricultural use* (all values mg/kg)

Soil Type/ Contaminant	Depth of contamination		
	Surface (<1m)	1m - 4m	> 4m
SAND			
C_{10}-C_{14}	58 (p)	560 (v)	650 (v)
C_{15}-C_{36}	4,000 (p)	> 20,000	> 20,000
SANDY SILT			
C_{10}-C_{14}	58 (p)	670 (v)	5,400 (v)
C_{15}-C_{36}	4,000 (p)	> 20,000	> 20,000
SILTY CLAY			
C_{10}-C_{14}	58 (p)	2,700 (v)	8,900 (v)
C_{15}-C_{36}	4,000 (p)	> 20,000	> 20,000
CLAY			
C_{10}-C_{14}	58 (p)	2,900 (v)	9,700 (v)
C_{15}-C_{36}	4,000 (p)	> 20,000	> 20,000
PUMICE			
C_{10}-C_{14}	58 (p)	1,100 (v)	1,800 (v)
C_{15}-C_{36}	4,000 (p)	> 20,000	> 20,000
PEATS AND HIGHLY ORGANIC SOILS			
C_{10}-C_{14}	58 (p)	> 20,000	> 20,000
C_{15}-C_{36}	4,000 (p)	> 20,000	> 20,000

NOTES:
1. Sample calculation presented in Table 4.21
2. Surrogate criteria based on PAH criteria presented in Table 4.10.
3. The following indicators denote the limiting pathway for each criterion: v - Volatilisation, p - Produce

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