Ministry for the
Environment
Manatū Mō Te Taiao

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

MODULE 5
Tier 1 groundwater acceptance criteria

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5 Tier 1 groundwater acceptance criteria

This module presents Tier 1 Groundwater screening criteria for a range of beneficial uses, and can provide the basis for the assessment and management of petroleum contaminated groundwater. The criteria are only applicable to releases of petroleum hydrocarbon products (e.g. gasoline, diesel, kerosene), not to pure solvents.

5.1 Overview

The module aims at the following objectives:

- establishment of the detailed procedure for the derivation of Tier 1 groundwater acceptance criteria
- development of Tier 1 groundwater acceptance criteria for selected contaminants for a range of beneficial uses
- development of a single set of groundwater screening criteria that may be used to indicate whether more detailed consideration is warranted; and
- establishment of an overall framework for the assessment of groundwater contamination and application of the Tier 1 groundwater acceptance criteria.

The detailed procedures presented may be used as the basis for the development of site-specific groundwater acceptance criteria (Tier 2) by incorporating site-specific information in place of the generic exposure assumptions used in the derivation of Tier 1 groundwater acceptance criteria.

As part of this module, Tier 1 groundwater acceptance criteria are presented for a range of beneficial uses:

- potable use
- stock watering
- irrigation
- aquatic ecosystem support.

In addition, consideration has been given to volatilisation of contaminants from groundwater underlying the site and the impact on users of the site. Comment on the relationship between the groundwater acceptance criteria and liquid phase hydrocarbons is given in Section 4.1.1 of Module 4.

Potable use criteria may be used as a conservative default for uses not explicitly considered as part of this module.

Particular reference has been made to the following documents:

- Ministry of Health, "*Drinking-water Standards for New Zealand"* (NZDWS), January, 1995. The guidelines for aesthetic determinants and standards for health-based determinants in the NZDWS (1995) provide the basis for nominating Tier 1 groundwater acceptance criteria for potable use.
- Ministry for the Environment, (1995) "*A Process for the Development of Guidelines for the Protection of Aquatic Life in New Zealand* ", 1995.

Risk-based criteria have been prepared for irrigation, stock watering and protection of surface uses of the site. In deriving these criteria, reference is made to the risk assessment methodologies presented

in Module 4 and in particular, the volatilisation modelling presented in Appendix 4D. Detailed procedures for the derivation of risk-based criteria are presented in the relevant appendices.

5.2 Framework for the assessment of groundwater contamination

An overall framework for the assessment of groundwater contamination is presented, including a basis for determining the requirement to sample groundwater and for identifying potential and actual uses of groundwater to be protected.

5.2.1 Overview

As outlined in Module 1, a framework for the assessment of groundwater contamination has been developed to assist in streamlining the site assessment process. The framework addresses two issues in particular:

- when sampling of groundwater is required
- what uses of the groundwater should be considered in assessing the significance of groundwater contamination.

5.2.2 Requirements for groundwater sampling

Groundwater monitoring should be implemented where there are reasonable grounds to suspect contamination has occurred and where it might affect an existing receptor (e.g. groundwater user) or a potential use of the aquifer.

Monitoring of groundwater quality should be undertaken whenever the potentially impacted aquifer is classified as sensitive i.e. where a use or potential use may be impacted and where groundwater is within 10 metres below a potential contaminant source (refer Section 5.2.3).

Groundwater contamination may be identified in the absence of significant identified soil contamination under a range of circumstances, including:

- where preferential pathways exist for migration of contamination
- where localised soil contamination exists resulting in failure to detect contamination despite a comprehensive soil sampling program
- where historical contamination has leached to the groundwater leaving minimal residual soil contamination.

Tier 1 soil acceptance criteria for the protection of groundwater quality have been developed for the purpose of assessing the potential future impact of residual soil contamination on groundwater quality (e.g. assessing the potential future impact of residual soil contamination on groundwater where the main source of existing contamination has been remediated).

The use of Tier 1 soil acceptance criteria for the protection of groundwater quality to assess whether groundwater contamination may have occurred, based on measurement of contaminant concentrations in soil only, is difficult for the reasons outlined above.

5.2.3 Definition of a sensitive aquifer

A sensitive aquifer is an aquifer that might be contaminated by a leak or spill of petroleum hydrocarbons (including leaching from contaminated soil resulting from a leak or spill) and which is subject to current or potential use[1] (including consideration of aquatic ecosystem support). A sensitive aquifer is defined here as an aquifer that is:

- not artesian (in practice true artesian or confined aquifers are unlikely to be encountered as part of the shallow groundwater systems normally of interest at petroleum contaminated sites); **and**
- less than 10 metres below the source or suspected source of contamination (or greater depth below ground surface where the geology suggests contamination may readily migrate to greater depth, e.g. clean sands or gravels, fractured basalts[2]); **and**
- is of a quality appropriate for use, can yield water at a useful rate and is in an area where extraction and use of groundwater may be reasonably foreseen. The definition of a useful rate depends on the potential use of the water. For example, a useful rate for a household may be 2000 L/day, whereas it would be much lower for irrigation or stock watering;

or

- where the source of contamination is less than 100 metres from a sensitive surface water body (i.e. a surface water body where limited dilution is available to mitigate the impact of contaminated groundwater discharging into the surface water body).

The first two conditions are designed to characterise the potential for an aquifer to be impacted by contamination, whereas the third condition is designed to reflect whether any potential or actual uses of the aquifer exist that require protection, either associated with extraction and use of the groundwater, or discharge of groundwater to a surface water body.

A distance of 100 metres between the contaminant source and a sensitive surface water body has been selected as reasonable a cut-off for possible impact of contaminated groundwater on surface water and its associated ecosystems. A distance of 100 metres has been selected because:

- Natural attenuation of dissolved phase hydrocarbon plumes generally limits the extent of such plumes. In the case of BTEX compounds, studies have shown that natural attenuation processes generally limit the extent of dissolved phase plumes to less than 100 metres, in all but clean sand and gravel aquifers.
- Free phase hydrocarbon plumes are generally limited in extent, particularly for retail and smaller depot sites which are likely to constitute the majority of sites considered.
- The impact of residual hydrocarbon contamination in groundwater on discharge to a surface water body is likely to be mitigated by dilution in all but the most sensitive receiving environments, e.g. wetlands.

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[1] The assessment of groundwater contamination in the first instance is based on the potential or actual use of groundwater. The priority and type of action taken in response to contamination depends on whether the use is currently being realised. Refer to discussion of resource management and risk assessment in Module 1.

[2] Where site geology suggests rapid migration of contaminants is possible, site-specific consideration should be given to the requirements for groundwater monitoring, including the depth below which impact on groundwater is not expected.

Dissolved phase petroleum hydrocarbons may extend further than 100 metres in some circumstances, although this is rare; typically, they are associated with rapid migration through clean sands or gravels. Anaerobic conditions can also slow the degradation of contaminants. In practice, the extent of any dissolved phase plume depends on a range of site-specific factors. Prediction of maximum likely plume extent on a site-specific basis is possible using tools developed for the evaluation of natural attenuation.

Where the receiving water body facilitates significant dilution of the groundwater discharged into it (e.g. large river systems, coastal water), sites within 100 metres of a surface water are unlikely to affect the surface water quality significantly, unless free phase hydrocarbon is present and migrating off-site. Frequently, dilution rates in the order of 1000:1 follow discharge of groundwater to surface water, resulting in contaminant concentrations less than criteria for the protection of aquatic ecosystems in the surface water after dilution, even when high dissolved phase concentrations are present. Under these conditions, some minor impact on the aquatic ecosystem within the dilution or mixing zone may occur.

More detailed consideration is required where groundwater discharges to a surface water body which does not provide a high degree of mixing and dilution (e.g. a wetland system).

5.2.4 Identification of potential uses of groundwater

The significance of groundwater contamination depends on the use to which the groundwater is to be put (this is analogous to the impact of land use on the significance of soil contamination). The potential uses of groundwater are defined in terms of the quality and yield of the groundwater and reflect the range of uses for which the groundwater may be suitable, irrespective of the land use or other constraints which may limit the likelihood of use for various purposes.

As indicated earlier, total dissolved solids concentration under 8000 mg/L may be used as a nominal threshold indicating the suitability of groundwater for extraction and use (in addition to the requirement to be able to sustain extraction of a useful rate). In addition, Table 5.1 presents general guidance on the uses potentially applicable to groundwater, based on salinity.

The application of Tier 1 groundwater acceptance criteria and the identification of beneficial uses to be protected is discussed in greater detail in Section 5.7.

Table 5.1 Range of acceptable total dissolved solids concentrations for potential uses of groundwater

Beneficial Use	Total dissolved solids (mg/L)							
	0-80	80-500	500-800	800-1000	501-1000	1001-3500	3501-8000	> 8000
Potable water - excellent	#							
Potable water - good	#	#						
Potable water - fair	#	#	#					
Potable water - poor	#	#	#	#	#			
Irrigation	#	#	#	#	#	#		
Stock water	#	#	#	#	#	#	#	
Aquatic ecosystem protection	#	#	#	#	#	#	#	#

Source: Adapted from EPAV, 1994 and MoH, 1996

5.3 Potable use

Tier 1 groundwater acceptance criteria for potable use are presented based on the Drinking-water Standards for New Zealand. Risk-based criteria for potable use have been derived where no value is nominated in the Drinking-water Standards for New Zealand.

5.3.1 Overview

Guideline values for contaminants in water intended for potable use are generally developed with reference to:

- the protection of public health, giving consideration to exposure via the ingestion of water, the inhalation of volatile compounds and absorption following direct contact
- the protection of the aesthetic quality of the water, e.g. odour, colour, staining
- the protection of water supply assets, e.g. corrosion of pipework.

Of these considerations, protection of public health is the primary concern. For the purposes of developing Tier 1 groundwater acceptance criteria for potable use, the guidelines for aesthetic determinants and standards for health-based determinants in the *Drinking-water Standards for New Zealand* (NZDWS) have been adopted, in accordance with Ministry of Health policy for drinking-water supplies, and are summarised in Table 5.2.

Table 5.2 Summary of Tier 1 acceptance criteria for potable use (all values in mg/L)

Contaminant	NZDWS	Estimated health-based criteria	Adopted[3]
Total Petroleum Hydrocarbons			
C_7 to C_9	-	(18)[4]	(18)[4,5]
C_{10} to C_{14}	-	>S[2]	(0.35)[5]
C_{15} to C_{36}	-	>S[2]	>S[2]
Aromatics			
Benzene	0.01		0.01
Toluene	0.8		0.8
Ethylbenzene	0.3		0.3
Xylenes	0.6		0.6
Polycyclic Aromatic Hydrocarbons			
Benzo(a)pyrene	0.0007		0.0007
Total	NAD[1]		NAD

Notes
1. No adequate data for derivation of guideline.
2. Criterion exceeds solubility limit.
3. Does not include consideration of aesthetic impact.
4. Benzene in fraction will be limiting.
5. Criterion exceeds solubility limit for most aliphatic hydrocarbons in this range.

Where no value is nominated in the NZDWS, reference has been made to the health risk assessment procedures to derive equivalent guideline values.

The health-based Maximum Acceptance Values (MAV) in the NZDWS are based on health risk assessment procedures as outlined in Section 5.3.2 for petroleum hydrocarbons. The NZDWS are based on the WHO (1995*) "Guidelines for Drinking-water Quality"* (refer to Appendix 4L for details of the toxicological evaluations underlying the WHO guidelines).

The derivation of the health-based MAVs presented in the NZDWS only considers exposure via the direct consumption of water (i.e. drinking). Exposure associated with, say, inhalation of volatile compounds and dermal absorption during bathing is not considered. Notwithstanding this, the health-based MAVs in the NZDWS have been adopted in New Zealand as Tier 1 groundwater acceptance criteria for potable use.

5.3.2 Derivation of health-based criteria for petroleum hydrocarbons

In the absence of health-based MAVs for petroleum hydrocarbons in the NZDWS, health-based screening criteria have been derived for the petroleum hydrocarbons using the procedures outlined in Module 4. The equation used for derivation of health-based screening criteria is:

$$\textbf{Acceptance criterion} = \frac{\textbf{Allowable Intake (mg/kg/day) x Body Weight (kg)}}{\textbf{Water Consumption Rate (L/day)}}$$

where Allowable Intake = (Reference Dose) x (Proportion of RfD assigned to drinking-water)

In accordance with the policies for the derivation of MAVs in the NZDWS (MoH, 1995), the derivation of health-based screening criteria for the petroleum hydrocarbons has been based on the following assumptions:

- Water Consumption Rate = 2 L/day
- Body Weight = 70 kg
- Proportion of RfD assigned to drinking-water = 0.1 (default assumption)[3]

For details of the Reference Doses for petroleum hydrocarbons, refer to Module 4. The health-based criteria for petroleum hydrocarbons are summarised in Table 5.3. Aesthetic impacts such as odour and taste tainting may be noted at concentrations below the health-based criteria nominated in Table 5.3 and should be assessed on a site-specific basis.

5.4 Stock watering

Tier 1 groundwater acceptance criteria for stock water use are presented, based on protection of stock health, human health and aesthetic quality. The impact of adverse aesthetic quality in the context of stock watering is uncertain.

5.4.1 Overview

The derivation of groundwater acceptance criteria for stock water use must include consideration of:

- protection of stock health
- palatability of the water for stock
- protection of human health via the consumption of livestock products.

In the absence of stock water quality guidelines in New Zealand for the contaminants of concern, reference may be made to guidelines released in other countries, particularly the ANZECC *"Australian Water Quality Guidelines for Fresh and Marine Waters*", 1992 (ANZECC). For most of

[3] Adopted as default position in the NZDWS i.e. 10% of the RfD assigned for drinking-water exposure. Adopted in this case to maintain consistency with NZDWS. Equivalent to adopting a HQ0.1.

the contaminants of concern at petroleum contaminated sites, the ANZECC guidelines indicate the potable use guideline values should be used as a conservative default.

Table 5.3 Summary of health-based groundwater acceptance criteria for petroleum hydrocarbons

Petroleum hydrocarbon fraction	Reference dose (mg/kg/day)	Acceptance criteria (mg/L)
C7 to C9	0.5	(18)[1]
C10 to C14	0.1	(0.35)[1]
C15 to C36	1.5	(5.3)[1]

Note
1. Exceeds solubility limits for most aliphatic hydrocarbons in this range.

5.4.2 Protection of stock health

Indicative acceptance criteria for the protection of stock health for compounds may be derived using an approach similar to that used for the derivation of Tier 1 acceptance criteria for potable use (refer Section 5.3). For the purposes of deriving indicative criteria, cattle have been selected as representative of livestock, as they exhibit a relatively high water consumption per unit body weight. Assumptions used in the derivation of criteria are as follows:

- body weight = 550 kg for cattle (Shell, 1994)
- water consumption rate = 55 L/day (for lactating cows) (Shell, 1994)

In deriving dose response factors for use in determining stock water screening criteria, based on those used in derivation of the potable use screening criteria, the following are assumed:

- cancer is not a relevant endpoint for the protection of cattle
- protection of sensitive sub-populations is not required to the same extent considered in human populations and therefore the safety factor (of 10) for intraspecies variability, incorporated in RfD estimates is reduced to a factor of 4.

On this basis, criteria for the protection of livestock health are presented in Table 5.4. Where the potable use criterion for a contaminant is based on a cancer endpoint assuming a non-threshold dose response relationship, an alternative endpoint has been selected. In particular, the criterion for benzene is based on the most stringent of the other monocyclic aromatic hydrocarbons, and a single criterion is nominated for the polycyclic aromatic hydrocarbons, rather than nominating a criterion specifically for benzo(a)pyrene.

Table 5.4 Groundwater acceptance criteria for stock watering based on livestock health

Contaminant		Acceptable intake (mg/kg/day)	Acceptance screening criteria (mg/L)
Monocyclic aromatic hydrocarbons	Benzene	0.4 (1)	4
	Toluene	0.8	8
	Ethylbenzene	0.4	4
	Xylenes	0.8	8
Total petroleum hydrocarbons	C7 to C9	20	>S(2)
	C10 to C14	0.4	(4)(4)
	>C15	6	>S
Polycyclic aromatic hydrocarbons	Naphthalene	0.016	0.16
	Pyrene (total PAHs)	0.12	1.2
	Benzo(a)pyrene	(0.12)3	>S

Notes
1. Based on ethylbenzene
2. Indicates indicative criterion exceeds solubility limit
3. Based on pyrene
4. Criterion exceeds solubility limit for most aliphatic hydrocarbons in this range.

5.4.3 Protection of human health

Humans may be exposed to contaminants in groundwater used for stock watering where the contaminants accumulate in edible portions of the animal, particularly in fat. Groundwater Acceptance Criteria for stock watering, based on the protection of human health, may be derived based on:

- correlations between the intake and the residue concentrations in cattle
- risk-based acceptance criteria for contaminant concentrations in livestock products, assuming 100% of livestock products consumed by an individual are from a contaminated source.

In order for contaminants to accumulate in livestock to a significant extent, the contaminants must be lipophilic and not readily metabolised. Most contaminants that are lipophilic are generally not present in groundwater at high concentrations. Monocyclic aromatic hydrocarbons, such as benzene, are only moderately lipophilic and are therefore unlikely to accumulate to a significant extent in livestock. Indicative groundwater acceptance criteria for stock watering based on the protection of human health are presented in Table 5.5 (refer to Appendix 5C for details).

The procedure outlined in Appendix 5C is based on published correlations which have been developed primarily using information on the bioaccumulation of chlorinated compounds, particularly pesticides, in livestock. Chlorinated compounds are generally more resistant to metabolism by mammals than are non-chlorinated compounds including benzo(a)pyrene. On this basis, published correlations may overestimate the extent of bioaccumulation of petroleum hydrocarbons by livestock. The indicative screening criteria presented in Table 5.5 are useful as a point of comparison, however a higher value has been selected as the Tier 1 acceptance criterion for benzo(a)pyrene in stock water, based on the considerations outlined above. In any case, the solubility of benzo(a)pyrene in water is low (0.0012 mg/LASTM, 1995) and therefore exposure is limited irrespective of the criterion nominated.

Table 5.5 Indicative groundwater acceptance criteria for stock watering based on human health

Contaminant		Indicative human health based acceptance criteria (mg/L)
Monocyclic aromatic hydrocarbons	Benzene	(560)[2]
	Toluene	>S[1]
	Ethylbenzene	>S
	Xylenes	>S
Total petroleum hydrocarbons	C_7 to C_9	>S
	C_{10} to C_{14}	>S
	C_{15} to C_{36}	>S
Polycyclic aromatic hydrocarbons	Benzo(a)pyrene	0.0003
	Total	>S

Notes
1. Denotes calculated criterion exceeds solubility limit.
2. Exceeds solubility of benzene in water when present as part of a gasoline mixture.

5.4.4 Summary of stock water acceptance criteria

The Tier 1 groundwater acceptance criteria for stock watering are summarised in Table 5.6. The calculations of the stock watering criteria indicate that, for petroleum fuel hydrocarbons, there is little potential for bioaccumulation in livestock to pose a significant threat to human health. Aesthetic considerations are found to be the limiting factor for most volatile components, however, these issues must be addressed separately on a site-specific basis.

The criteria presented in Table 5.6 are based on livestock and human health only. No assessment of the palatability of the water, or other aesthetic impacts has been made. No reliable information was identified for livestock regarding the palatability of water containing petroleum hydrocarbons, and therefore any assessment would need to be site-specific.

Table 5.6 Tier 1 groundwater acceptance criteria for stock watering

Contaminant		Screening criteria for stock watering (mg/L)			
		Potable[5]	Livestock health	Human health	Adopted[4]
Monocyclic aromatic hydrocarbons	Benzene	0.01	4	>S[1] (560)	4
	Toluene	0.8	8	>S	8
	Ethylbenzene	0.3	4	>S	4
	Xylenes	0.6	8	>S	8
Total petroleum hydrocarbons	C7 to C9	(18)[6]	>S	>S	S[3]
	C10 to C14	(0.35)[6]	(4)[6]	>S	(4) [3],[6]
Polycyclic aromatic hydrocarbons	C15 to C36	(5.3)[6]	>S	>S	S[3]
	Naphthalene		0.16	>S	0.16
	Benzo(a)pyrene	0.0007	>S	0.0003	0.001[2]
	Total (pyrene)		1.2	>S	1.2

Notes
1. >S indicates calculated criterion exceeds solubility limit of compound when present in a gasoline mixture.
2. Higher value adopted based on metabolism of PAHs reducing accumulation, refer discussion above.
3. Concentration in water should not exceed solubility limit, based on sheen formation.
4. Site-specific assessment of aesthetic impact required. Some irritation of eyes and other membranes may possibly be noted in cattle during drinking.
5. Presented for comparison only.
6. Exceeds solubility limit for most aliphatic hydrocarbons in this range.

Similarly, some irritation of the eyes or other membranes of cattle may occur during drinking (where groundwater is contaminated by volatile petroleum compounds), but no published information was

identified in this regard. Livestock are generally acknowledged to be relatively tolerant of water quality and aesthetic impact in particular, but this may become limiting in some circumstances.

5.5 Irrigation use

Tier 1 groundwater acceptance criteria for irrigation use, either agricultural or residential, have been derived on consideration of volatilisation losses (assuming spray application), aesthetic impact and protection of human health.

Published information is available regarding the effects of some contaminants in irrigation water on plant health, particularly relating to the heavy metals and other inorganics. Very little published information is available regarding the effects on plant life or human health of organic contaminants in irrigation water. The ANZECC guidelines indicate that for organic contaminants the guideline values for potable use should be used as a default.

A protocol for the development of acceptance criteria for irrigation water has been developed by BP (Walden and Spence1996). Tier 1 groundwater acceptance criteria for irrigation use have been developed using this protocol (with modified exposure assumptions, to be consistent with the derivation of other acceptance criteria). The key elements of the protocol are presented in Appendix 5A.

The protocol has been developed in the context of domestic spray irrigation but also has more general application.

The protocol considers:

- contaminant loss by volatilisation due to spray irrigation
- inhalation of vapours by site users
- dermal absorption and ingestion of water by children playing under sprinklers
- uptake of contaminants applied in irrigation water by plants and consumption of home-grown produce.

The procedure for developing irrigation water criteria incorporates a number of simplifying assumptions that suggest the derived criteria are likely to be conservative. In particular, the protocol assumes:

- no degradation, leaching or volatile losses of contaminants once they have entered the soil environment
- no metabolism or degradation of contaminants within the plant
- contaminant concentrations in water within plants equal those in the irrigation water entering the soil (after spray volatilisation losses)
- no binding of contaminants to soils.

The protocol is most applicable to the volatile, relatively soluble compounds such as the BTEX components. The assumptions that contaminants do not bind to soil particles and that the concentration of contaminants in the plant moisture is equal to that in the irrigation water are likely to overestimate exposure and result in conservative acceptance criteria for less soluble compounds such

as benzo(a)pyrene. In practice, benzo(a)pyrene and other PAHs are expected to preferentially bind to organic carbon in the soil environment, thus reducing uptake.

The Tier 1 groundwater acceptance criteria based on irrigation use are presented in Table 5.7, and details of their derivation are presented in Appendix 5A.

Table 5.7 Tier 1 groundwater acceptance criteria for irrigation use (mg/L)

Contaminant	Aesthetic[1]	Irrigation	Adopted
Monocyclic aromatic hydrocarbons			
Benzene	160	0.8	0.8
Toluene	300	39	39
Ethylbenzene	340	18	18
Xylenes	13	31	13
Total petroleum hydrocarbons			
C_7 to C_9 (n-hexane)		>S[2]	>S
C_9 to C_{14}		(1.8)[3]	(1.8)[3]
C_{15} to C_{36}		>S	>S
Polycyclic aromatic hydrocarbons			
Naphthalene	9	0.8	0.8
Pyrene (non-carcinogenic PAHs)		2	2
Benzo(a)pyrene		0.0004	0.001

Notes
1. Based on exceedance of reported odour threshold in ambient air, as predicted using the shower model (refer Appendix 5A). Criteria presented are based on odour associated with individual compounds. The combined effect of multiple compounds may result in some odour impact at concentrations below those listed above.
2. >S indicates that the calculated criterion exceeds the solubility limit for the compound.
3. Exceed the solubility limit for aliphatic hydrocarbons in this range.

The adopted Tier 1 groundwater acceptance criteria for irrigation use have been selected based on protection of human health where exposure occurs through the consumption of produce, dermal contact with water used for irrigation and inhalation of volatile compounds. Possible odour impacts in ambient air associated with spray irrigation of water containing hydrocarbons are also considered.

Lower criteria may be appropriate on a site-specific basis because:

- Aesthetic impact associated with individual compounds is likely to be additive when present ix mixture.
- Odour may be noted near the spraying, rather than downwind in the ambient air.
- Protection of plant life and terrestrial ecosystems may be required. In practice, volatilisation losses, adsorption on soil particles, rapid degradation in the surface soil environment and the requirement to provide only a general level of protection to soil organisms (rather than protection of a pristine environment) means that the proposed guidelines may not adversely affect plant life. This requires confirmation.

The adopted criterion for benzo(a)pyrene is higher than that predicted using the model presented in Appendix 5A. In practice, contrary to the assumptions underlying the model (which are more appropriate for the more soluble compounds) benzo(a)pyrene is expected to bind strongly to soil particles, quickly reducing the concentration in soil moisture and reducing plant uptake. The adopted criterion is based on professional judgement given the results of the calculations[4]. The adopted value

[4] The adopted value is 2.5 times the calculated value. The calculation procedure was designed for volatile organics and therefore is expected to over predict uptake of heavier PAHs such as benzo(a)pyrene. The calculated value is lower than the value for potable use and therefore the adoption of a value used Tier 1 criteria is considered pragmatic while maintaining the protection of human health.

is similar to the potable criterion and the solubility of benzo(a)pyrene in water, which would further limit possible exposure.

5.6 Aquatic ecosystem support

The 1992 ANZECC water quality guidelines are currently being revised with input from the Ministry for the Environment and New Zealand scientists. The new ones are not expected to be available until mid-2000. In the absence of definitive New Zealand guidance regarding the protection of ecosystems, guideline values nominated by a number of agencies have been summarised in Table 5.8. These include:

- Australian and New Zealand Environment and Conservation Council (ANZECC, 1992)
- United States Environmental Protection Agency (USEPA, 1995)
- Council of Canadian Ministers for the Environment (CCME, 1991).

In general, the USEPA and Canadian guidelines for the protection of aquatic ecosystems are designed to provide effectively full protection to a relatively pristine environment, based on an understanding of no significant adverse effect. Each of agency defines this concept slightly differently, however, and the data sets underlying each set of guidelines are also expected to differ.

An important aspect of the revised ANZECC guidelines for the protection of aquatic ecosystems is that they will incorporate information regarding New Zealand aquatic species, where available.

Table 5.8 Summary of guidelines for the protection of aquatic ecosystems

Contaminant	Guideline values (mg/L)		
	Australia[1]	USA[2]	Canada[3]
Monocyclic aromatic hydrocarbons			
Benzene	0.3	5.3	0.3
Ethylbenzene	0.14	32	-
Toluene	0.3	17.5[(4)]	0.3
Xylenes	-	-	-
Total petroleum hydrocarbons			
C_6 to C_9	-	-	-
C_{10} to C_{14}	-	-	-
$>C_{15}$	-	-	-
Polycyclic aromatic hydrocarbons			
Naphthalene	-	0.62	-
Benzo(a)pyrene	-	-	ID
Total	0.003	2.3	ID

Notes
1. ANZECC 1992
2. USEPA 1995 guidelines values are from freshwater acute lowest effect concentrations (LEC)
3. CCME 1991
4. Toluene marine acute and chronic LECs (mg/L) are 6.3 and 5.0 respectively.

ID Insufficient data

5.7 Protection of surface use of the site

Tier 1 groundwater acceptance criteria for protection of surface users of the land are presented and based on volatilisation modelling and protection of human health. Criteria for a range of soils and depths to groundwater, have been developed.

In addition to protecting direct and indirect uses of the groundwater (e.g. potable and ecosystem support), it is necessary to consider possible impacts of groundwater contamination on the surface use of the site, e.g. residential or commercial/industrial. In the context of contamination at petroleum contaminated sites, concern may be associated with odour and health impacts resulting from the volatilisation of contaminants in the groundwater.

The impact of groundwater contamination on the health of users of the site depends on considering a range of chemical and site-specific factors, including:

- soil type (porosity, moisture content, organic carbon content, density)
- depth to groundwater
- site use (e.g. agricultural, residential, commercial/industrial)
- volatility and phase partitioning of the contaminant (vapour pressure, Henry's Law co-efficient, organic carbon-water partition co-efficient, air diffusivity)

Tier 1 groundwater acceptance criteria based on protecting the health of users of the site may be derived using health-risk assessment techniques such as those outlined in Module 4. Procedures for estimating the contaminant concentrations in indoor and outdoor air, based on the volatilisation of contaminants from groundwater, are presented in Appendix 4D (refer to Module 4 for a general discussion of volatilisation modelling and information on the assumed soil properties). These procedures are analogous to those used in Module 4 to estimate the volatilisation of contaminants from contaminated soil.

Exposure to contaminants in groundwater via the inhalation of volatile compounds released on-site, may be estimated as follows:

$$\mathbf{CDI = \frac{IH \times C_w \times VF_{gw} \times EF \times ED}{AT \times BW}}$$

where:

CDI	=	Chronic Daily Intake (mg/kg/day)
C_w	=	Contaminant concentration in groundwater (mg/L)
VF_{gw}	=	Volatilisation Factor for groundwater (L/m^3)
EF	=	Exposure Frequency (day/year)
AT	=	Averaging Time (day)
IH	=	Inhalation Rate (m^3/day)
ED	=	Exposure duration (year)
BW	=	Body weight (kg)

The Volatilisation Factor relates the contaminant concentrations in groundwater to possible contaminant concentrations in air within the breathing zone of the receptor. The Volatilisation Factor incorporates consideration of soil type, building type and depth to groundwater. For details of the derivation of the Volatilisation Factor for emissions from groundwater refer to Appendix 4D.

Exposure assumptions related to the site user (e.g. inhalation rate), site use (e.g. type of building) and soil type (e.g. porosity) are consistent with those assumed in the derivation of Tier 1 soil acceptance criteria based on the inhalation of volatile compounds.

Tier 1 groundwater acceptance criteria based on the protection of surface uses of the site are highly dependent on the assumed site conditions, in particular, the depth to groundwater. Tier 1 groundwater acceptance criteria based on protection of surface use of the site have been derived for a range of depths to groundwater::

- 2 - 4 metres
- 4 - 8 metres
- > 8 metres

The depth ranges were selected as being representative of those encountered at sites where volatilisation of contaminants may be of concern. Where the depth to groundwater exceeds 8 metres, the criteria developed for a depth of 8 metres may be used as a conservative starting point. Where groundwater is shallower than 2 metres, a linear extrapolation based on criteria at 2, 4 and 8 metres may be used.

The volatilisation of contaminants from groundwater is also highly dependent on the properties of the overlying soil. Soil properties consistent with those assumed for estimating the volatilisation of contaminants from soil (refer Module 4) have been adopted.

Eight soil profiles have been assumed for the purposes of deriving Tier 1 groundwater acceptance criteria based on the protection of surface uses of the site. The profiles are briefly described as follows (refer to Module 4 for more detailed descriptions, including assumed properties):

- sand, silty sands
- silt, sandy silts, clayey sand
- silty clay, sandy clay
- clay
- pumice
- peats and other organic soils
- fractured basalt overlain by 1 metre of silty clay
- gravels overlain by 1 metre of silt.

A finer-grained soil was assumed to overlie. the fractured basalt and gravels as these formations rarely extend intact from the groundwater to the surface; if uniform profile is assumed, the rate of volatilisation may be significantly overestimated.

Tier 1 groundwater acceptance criteria based on the protection of surface uses of the site are summarised in Tables 5.9 and 5.10.

In the context of ongoing use of a site as a petroleum handling facility, volatilisation from soil and groundwater may be less important since occupational exposure limits nominated by Occupational Safety and Health, rather than risk-based limits may be used as the target air concentrations..

5.8 Tier 1 groundwater acceptance criteria and the assessment of groundwater contamination

Tier 1 groundwater acceptance criteria are presented for a range of beneficial uses. International guidelines for ecosystem protection are presented for information pending revision of the 1992 ANZECC water quality guidelines. The application of Tier 1 groundwater acceptance criteria to the assessment of groundwater contamination is also discussed.

5.8.1 Tier 1 groundwater acceptance criteria

Tier 1 groundwater acceptance criteria for BTEX and PAHs are presented in Table 5.11 for a range of beneficial uses. Tier 1 groundwater acceptance criteria for TPH are presented in Table 5.12. As for soil criteria, assessment of risk based on TPH should be considered secondary compared to assessments based on individual compounds (e.g. BTEX). The Tier 1 groundwater acceptance criteria have been developed in a manner generally consistent with the derivation of the Tier 1 soil acceptance criteria, with the exception of criteria for potable use, where the NZDWS have been adopted.

Tier 1 groundwater acceptance criteria for the protection of aquatic ecosystems have not been nominated. As discussed in Section 5.2, the discharge of contaminated groundwater from a petroleum contaminated site to a surface water body rarely has a significant impact on the ecosystems associated with the surface water, unless;

- the dilution of groundwater on discharge to the surface water is limited (e.g. discharge to a wetland)
- the contaminated site is immediately adjacent to the surface water body; and/or
- free product discharges to the surface water body.

In the absence of New Zealand guidance regarding the protection of aquatic ecosystems, the ANZECC guideline values have been presented in Table 5.11 for information.

Whereas exceedance of most Tier 1 acceptance criteria does not indicate clean-up is necessarily required (but rather that more detailed consideration may be warranted), it is not appropriate to derive Tier 2 groundwater acceptance criteria for potable use that are less stringent than the NZDWS. The NZDWS define the suitability of water for potable use in New Zealand, nominating MAVs (Maximum Acceptable Values) which represent the concentration of a contaminant which, on the basis of present knowledge, is not considered to cause any significant risk to the health of consumers over a lifetime of consumption of the water. The MAVs, together with the monitoring and compliance requirements set out in the NZDWS, define the suitability of a water supply for potable use, and therefore may not be subject to Tier 2 or 3 assessment, as may be the case with other considerations.

5.8.2 Assessment of groundwater contamination

In application of Tier 1 groundwater acceptance criteria to the assessment of groundwater contamination, consideration must be given to the provisions of the Resource Management Act 1991, particularly in relation to the protection of aquatic ecosystems and the management of groundwater resources. The Tier 1 acceptance criteria are designed to represent maximum allowable contaminant concentrations determined on a risk basis (using conservative exposure assumptions). The managers of groundwater resources, however, also have an objective of managing resources in such a way as to

minimise degradation and maximise possible future use. In some circumstances the two objectives may be opposing and therefore careful consideration is required as part of the risk management decision-making process as part of the risk-based approach to site assessment and management.

A framework for the assessment of groundwater contamination is presented in Figure 1.4 of Module 1 (reproduced in this module as Figure 5.1).

Important steps in the application of the Tier 1 groundwater acceptance criteria are outlined as follows:

- The nature and quality of each aquifer potentially affected by petroleum contamination should be critically reviewed to assess the potential uses of the groundwater (refer Table 5.1). Salinity is a measure of the natural groundwater quality used to define the potential uses of the groundwater. The yield of an aquifer may also affect its potential for some direct uses.
- The actual uses of the groundwater should be carefully reviewed to determine the potential for any immediate impact or risk. This may be linked with preliminary fate and transport assessment to assist in determining whether contamination identified in groundwater is likely to migrate and impact on existing uses. While groundwater managers are frequently reluctant to distinguish between potential and actual uses of the groundwater in determining whether an aquifer has been adversely impacted (and therefore in determining the requirement for remediation), whether the aquifer is currently being used is important in determining the urgency of action. For example, if groundwater is contaminated but it is not currently being used for any purpose (even though a potential use exists), then a strategy based on source removal or control, monitoring and natural attenuation may be accepted. In contrast, if the quality of existing groundwater presently in use is under immediate threat then more immediate action may be warranted.
- In the first instance, Tier 1 groundwater acceptance criteria presented in Table 5.11 may be compared with contaminant concentrations in groundwater at the site. However, as part of the Tier 1 assessment, the acceptance criteria based on extraction of groundwater should be applied at the nearest existing user in order to estimate the current risk, and the nearest point of likely extraction and use in order to characterise the possible future impact of contamination.

  In the case of acceptance criteria based on volatilisation, comparison with contaminant concentrations in groundwater beneath the site may be more appropriate. As discussed in Module 4, before relying on criteria developed on the basis of volatilisation modelling, a review of exposure pathways should be completed to determine whether migration of volatile compounds into indoor air is likely to occur. Where volatilisation is predicted to be the governing pathway, consideration should be given to measuring soil gas or indoor air concentrations for comparison with targets nominated in Appendix 4H and Appendix 4J.

  Similarly, where a site is to be redeveloped for a use that may involve extraction and use of groundwater on site, comparison of the Tier 1 criteria with contaminant concentrations in groundwater beneath the site may be appropriate in order to indicate the possible future risk.

- As part of the risk management process and assessment of the urgency of any corrective action, a distinction should be made between the actual risk to current users of the groundwater and the possible future risk. The risk associated with possible future use of the groundwater indicates the requirement for some action e.g. monitoring natural attenuation, and is consistent with resource management objectives. In contrast, the risk to existing users defines the urgency of action, (refer to Module 1 for a further discussion of risk-based decision making in the context of resource management).

As discussed earlier, the impact of contaminated groundwater discharging to surface water is expected to be limited in most cases due to the impact of attenuation of contaminants between the source and the discharge point and the dilution on discharge to surface water. If impact on surface water quality is suspected, the Tier 1 groundwater acceptance criteria and, in the interim, the ANZECC guidelines for ecosystem protection may be used to assess the impact. The process for the assessment of impact on surface water is similar to that for groundwater. The beneficial uses to be protected must first be nominated based on the nature of the surface water body. Estimated or measured contaminant concentrations in the surface water may then be compared with the relevant criteria. Contaminant concentrations in the surface water body may be estimated based on measured concentrations in groundwater after accounting for attenuation between the source and the point of discharge, and dilution of groundwater on discharge to the surface water.

Figure 5.1 Framework for the assessment of groundwater contamination

Table 5.9 Route specific groundwater acceptance criteria INHALATION PATHWAY
Residential / agricultural use
(all values in mg/kg)

Soil Type/ Contaminant	Depth to Contaminated Groundwater					
	2 m		4 m		8 m	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
SAND						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	1.1	(77) [2]	1.1	(85) [2]	1.2	(100) [2]
Toluene	(140) [2]	S [1]	(150) [2]	S [1]	(160) [2]	S [1]
Ethylbenzene	(35) [2]	S [1]	(36) [2]	S [1]	(40) [2]	S [1]
Xylenes	(120) [2]	S [1]	(130) [2]	S [1]	(140) [2]	S [1]
PAHs						
Naphthalene	22	S [1]	24	S [1]	27	S [1]
Non-carc. (Pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
SANDY SILT						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	3.6	(450) [2]	3.8	(490) [2]	4.3	(570) [2]
Toluene	(500) [2]	S [1]	(530) [2]	S [1]	S [1]	S [1]
Ethylbenzene	(130) [2]	S [1]	(140) [2]	S [1]	(150) [2]	S [1]
Xylenes	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PAHs						
Naphthalene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Non-carc. (pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
SILTY CLAY						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	13	S [1]	22	S [1]	40	S [1]
Toluene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Ethylbenzene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Xylenes	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PAHs						
Naphthalene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Non-carc. (pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]

NOTE:
1. Calculated water criteria exceeds solubility limit for pure compound in water.
2. Values in brackets exceed solubility limit for compound in water when present as part of a typical gasoline mixture. Solubility is dependent upon composition of the gasoline mixture and so uncertainty arises as to the actual solubility limit of a mixture in water. For further explanation refer to Appendix 4M of Module 4.
3. Measured TPH concentrations in groundwater are frequently dominated by the aromatic component of the TPH mixture. The aliphatic component of TPH, as addressed below, generally exhibits very low solubility.

Table 5.9 (CONTINUED)
Route specific groundwater acceptance criteria INHALATION PATHWAY
***Residential / agricultural use* (all values in mg/kg)**

Soil Type/ Contaminant	Depth to Contaminated Groundwater					
	2m		4m		8m	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
CLAY						
TPHs (3)						
C_7-C_9	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
C_{10}-C_{14}	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
C_{15}-C_{36}	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
MAHs						
Benzene	20	S (1)	42	S (1)	(86) 2	S (1)
Toluene	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
Ethylbenzene	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
Xylenes	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
PAHs						
Naphthalene	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
Non-carc. (Pyrene)	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
Benzo(a)pyrene	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
PUMICE						
TPHs (3)						
C_7-C_9	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
C_{10}-C_{14}	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
C_{15}-C_{36}	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
MAHs						
Benzene	5.0	(670) (2)	5.3	(710) (2)	5.8	(790) (2)
Toluene	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
Ethylbenzene	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
Xylenes	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
PAHs						
Naphthalene	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
Non-carc. (Pyrene)	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
Benzo(a)pyrene	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
PEATS AND HIGHLY ORGANIC SOILS						
TPHs (3)						
C_7-C_9	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
C_{10}-C_{14}	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
C_{15}-C_{36}	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
MAHs						
Benzene	3.4	(430) (2)	3.5	(450) (2)	3.8	(490) (2)
Toluene	(490) (2)	S (1)	(500) (2)	S (1)	S (1)	S (1)
Ethylbenzene	(130) (2)	S (1)	(130) (2)	S (1)	(140) (2)	S (1)
Xylenes						
PAHs						
Naphthalene	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
Non-carc. (Pyrene)	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)
Benzo(a)pyrene	S (1)	S (1)	S (1)	S (1)	S (1)	S (1)

NOTE:
1. Calculated water criteria exceeds solubility limit for pure compound in water.
2. Values in brackets exceed solubility limit for compound in water when present as part of a typical gasoline mixture. Solubility is dependent upon composition of the gasoline mixture and so uncertainty arises as to the actual solubility limit of a mixture in water. For further explanation refer to Appendix 4M.
3. Measured TPH concentrations in groundwater are frequently dominated by the aromatic component of the TPH mixture. The aliphatic component of TPH, as addressed below, generally exhibits very low solubility.

Table 5.9 (CONTINUED)
Route specific groundwater acceptance criteria INHALATION PATHWAY
***Residential / agricultural use* (all values in mg/kg)**

Soil Type/ Contaminant	Depth to Contaminated Groundwater					
	2m		4m		8m	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
FRACTURED BASALTS						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	5.2	(700) [2]	5.4	(730) [2]	5.9	(800) [2]
Toluene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Ethylbenzene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Xylenes	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PAHs						
Naphthalene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Non-carc. (Pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
GRAVELS						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	1.1	(76) [2]	1.1	(81) [2]	1.2	(92) [2]
Toluene	(140) [2]	S [1]	(140) [2]	S [1]	(150) [2]	S [1]
Ethylbenzene	(33) [2]	S [1]	(34) [2]	S [1]	(36) [2]	S [1]
Xylenes	(120) [2]	S [1]	(120) [2]	S [1]	(130) [2]	S [1]
PAHs						
Naphthalene	26	S [1]	27	S [1]	29	S [1]
Non-carc. (pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]

NOTE:
1. Calculated water criteria exceeds solubility limit for pure compound in water.
2. Values in brackets exceed solubility limit for compound in water when present as part of a typical gasoline mixture. Solubility is dependent upon composition of the gasoline mixture and so uncertainty arises as to the actual solubility limit of a mixture in water. For further explanation refer to Appendix 4M.
3. Measured TPH concentrations in groundwater are frequently dominated by the aromatic component of the TPH mixture. The aliphatic component of TPH, as addressed below, generally exhibits very low solubility.

Table 5.10 Route specific groundwater acceptance criteria INHALATION PATHWAY
Commercial / industrial use
(all values in mg/L)

Soil Type/ Contaminant	Depth to Contaminated Groundwater					
	2m		4m		8m	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
SAND						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	5.2	(340) [2]	5.5	(370) [2]	6.0	(450) [2]
Toluene	(460) [2]	S [1]	(480) [2]	S [1]	530	S [1]
Ethylbenzene	(110) [2]	S [1]	(120) [2]	S [1]	(130) [2]	S [1]
Xylenes	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PAHs						
Naphthalene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Non-carc. (Pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
SANDY SILT						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	18	S [1]	19	S [1]	21	S [1]
Toluene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Ethylbenzene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Xylenes	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PAHs						
Naphthalene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Non-carc. (pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
SILTY CLAY						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	(64) [2]	S [1]	(110) [2]	S [1]	(200) [2]	S [1]
Toluene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Ethylbenzene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Xylenes	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PAHs						
Naphthalene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Non-carc. (pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]

NOTE:
1. Calculated water criteria exceeds solubility limit for pure compound in water.
2. Values in brackets exceed solubility limit for compound in water when present as part of a typical gasoline mixture. Solubility is dependent upon composition of the gasoline mixture and so uncertainty arises as to the actual solubility limit of a mixture in water. For further explanation refer to Appendix 4M of Module 4.
3. Measured TPH concentrations in groundwater are frequently dominated by the aromatic component of the TPH mixture. The aliphatic component of TPH, as addressed below, generally exhibits very low solubility.

Table 5.10 (CONTINUED)
Route specific groundwater acceptance criteria INHALATION PATHWAY
***Commercial / industrial use* (all values in mg/L)**

Soil Type/ Contaminant	Depth to Contaminated Groundwater					
	2m		4m		8m	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
CLAY						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	(100) [2]	S [1]	(210) [2]	S [1]	(430) [2]	S [1]
Toluene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Ethylbenzene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Xylenes	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PAHs						
Naphthalene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Non-carc. (Pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PUMICE						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	25	S [1]	26	S [1]	29	S [1]
Toluene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Ethylbenzene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Xylenes	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PAHs						
Naphthalene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Non-carc. (Pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PEATS AND HIGHLY ORGANIC SOILS						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	17	S [1]	17	S [1]	19	S [1]
Toluene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Ethylbenzene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Xylenes	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PAHs						
Naphthalene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Non-carc. (Pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]

NOTE:
1. Calculated water criteria exceeds solubility limit for pure compound in water.
2. Values in brackets exceed solubility limit for compound in water when present as part of a typical gasoline mixture. Solubility is dependent upon composition of the gasoline mixture and so uncertainty arises as to the actual solubility limit of a mixture in water. For further explanation refer to Appendix 4M.
3. Measured TPH concentrations in groundwater are frequently dominated by the aromatic component of the TPH mixture. The aliphatic component of TPH, as addressed below, generally exhibits very low solubility.

Table 5.10 (CONTINUED)
Route specific groundwater acceptance criteria INHALATION PATHWAY
***Commercial / industrial use* (all values in mg/L)**

Soil Type/ Contaminant	Depth to Contaminated Groundwater					
	2m		4m		8m	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
FRACTURED BASALTS						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	26	S [1]	27	S [1]	29	S [1]
Toluene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Ethylbenzene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Xylenes	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PAHs						
Naphthalene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Non-carc. (Pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
GRAVELS						
TPHs [3]						
C_7-C_9	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{10}-C_{14}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
C_{15}-C_{36}	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
MAHs						
Benzene	5.2	(330) [2]	5.4	(360) [2]	5.7	(400) [2]
Toluene	(450) [2]	S [1]	(460) [2]	S [1]	(490) [2]	S [1]
Ethylbenzene	(110) [2]	S [1]	(110) [2]	S [1]	(120) [2]	S [1]
Xylenes	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
PAHs						
Naphthalene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Non-carc. (Pyrene)	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]
Benzo(a)pyrene	S [1]	S [1]	S [1]	S [1]	S [1]	S [1]

NOTE:
1. Calculated water criteria exceeds solubility limit for pure compound in water.
2. Values in brackets exceed solubility limit for compound in water when present as part of a typical gasoline mixture. Solubility is dependent upon composition of the gasoline mixture and so uncertainty arises as to the actual solubility limit of a mixture in water. For further explanation refer to Appendix 4M.
3. Measured TPH concentrations in groundwater are frequently dominated by the aromatic component of the TPH mixture. The aliphatic component of TPH, as addressed below, generally exhibits very low solubility.

Table 5.11 Tier 1 Groundwater acceptance criteria (mg/L) (1)

Contaminant	Tier 1 Groundwater Acceptance Criteria			Aquatic ecosystem guidelines (ANZECC, 1992)
	Potable	Irrigation (2)	Stock water (2)	
MAHs				
Benzene	0.01	0.8	4	0.3
Toluene	0.8	39	8	0.3
Ethylbenzene	0.3	18	4	0.14
Xylenes	0.6	13	8	-
PAHs				
Naphthalene	-	0.8	0.16	-
Non-carc.(Pyrene)	-	2	1.2	-
Benzo(a)pyrene	0.0007	0.001	0.001	-
Total PAH	NAD 3			0.003

NOTE:
1. Refer to Tables 5.9 and 5.10 for Tier 1 groundwater acceptance criteria based on volatilisation and impact on surface users of the site.
2. Values uncertain, based on cross media transfer estimates. Refer Sections 5.4 and 5.5.
3. NAD denotes Not Adequate Data (MoH, 1995)

Table 5.12 Tier 1 Groundwater acceptance criteria for TPH (mg/L) (1)

Contaminant	Tier 1 Groundwater Acceptance Criteria			Aquatic ecosystem guidelines (ANZECC, 1992)
	Potable	Irrigation (3)	Stock water (3)	
C_7 - C_9	18 (4)	> S (2)	> S (2)	-
C_{10} - C_{14}	> S (2)	> S (2)	> S (2)	-
C_{15} - C_{36}	> S (2)	> S (2)	> S (2)	-

NOTE:
1. Refer to Tables 5.9 and 5.10 for Tier 1 groundwater acceptance criteria based on volatilisation.
2. > S denotes calculated limit exceeds solubility limit given TPH criteria based on aliphatic component only. Separate consideration is given to the aromatic component.
3. Values uncertain, based on cross media transfer estimates.
4. Exceeds solubility limit for aliphatic components; aromatic components will be limited by criteria for BTEX compounds. Therefore, comparison of measured concentrations with criteria for BTEX, will also be protective against adverse effects associated with aliphatic component.

5.9 References and further reading

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[5] Paper intended for publication in a peer reviewed journal is currently in preparation.